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Paleoecological Studies

of South Florida

edited by

Bruce R. Wardlaw

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CHAPTER 1

INTRODUCTION TO PALEOECOLOGICAL STUDIES OF SOUTH FLORIDA AND THE IMPLICATIONS FOR LAND MANAGEMENT DECISIONS

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ABSTRACT

The Florida Everglades developed from the interplay of sea level and climate. The subtle balance of these two factors over the last two millennia is important to understanding restoration strategies. During the Medieval Warm Period and the Little Ice Age, the Everglades showed a general drying trend. The Medieval Warm Period trend was due to a significant decrease in annual precipitation while sea level was rising. The Little Ice Age trend was due to the combined effect of reduced precipitation and the slowing in the relative rate of sea level rise. This failure to keep base level with Everglades sediment and peat accumulation, yielded shorter hydroperiods and dryer conditions. Sea level has been steadily rising over the last century and should be considered in water flow modeling. Land use and water management practices over the last century have greatly partitioned the Everglades, compounding its ability to respond ecosystem-wide in predictable ways to climate and sea level change.

Salinity in Florida Bay is affected by marine circulation, climate (rainfall) and runoff. Marine circulation was reduced in the early 20th century by intense railroad, highway, and bridge construction connecting the Keys. Rainfall and runoff appeared coupled early in the 1900's and has slowly been decoupled throughout the last century, especially after 1970. A restoration goal should be to couple rainfall and runoff again. Salinity in central, western and southern (Atlantic transitional) zones is influenced by direct rainfall; salinity in the northern (northern transitional) and eastern zones is influenced to a large extent by runoff. These latter zones need to be monitored to ascertain that rainfall and runoff are indeed coupled to the degree that they have been in the past.

Salinity can be predicted for specific sites in Florida Bay following known rainfall months.

INTRODUCTION

The South Florida ecosystem has undergone dynamic changes over the last century but most of these are known only by analogy. Can paleoecological studies fill this important information gap? Yes, detailed paleoecological studies provide the retrospective information to understand the course and cause of these changes. Can this information influence and be utilized by decision makers? Yes, this information enables a more coherent scientific foundation on which to base policies and decisions.

This volume offers a wide variety of paleoecological studies in many different areas of South Florida. The area of study and the techniques utilized affect the conclusions which vary from local and qualitative to widespread and quantitative. The underlying data for interpretation are invaluable.

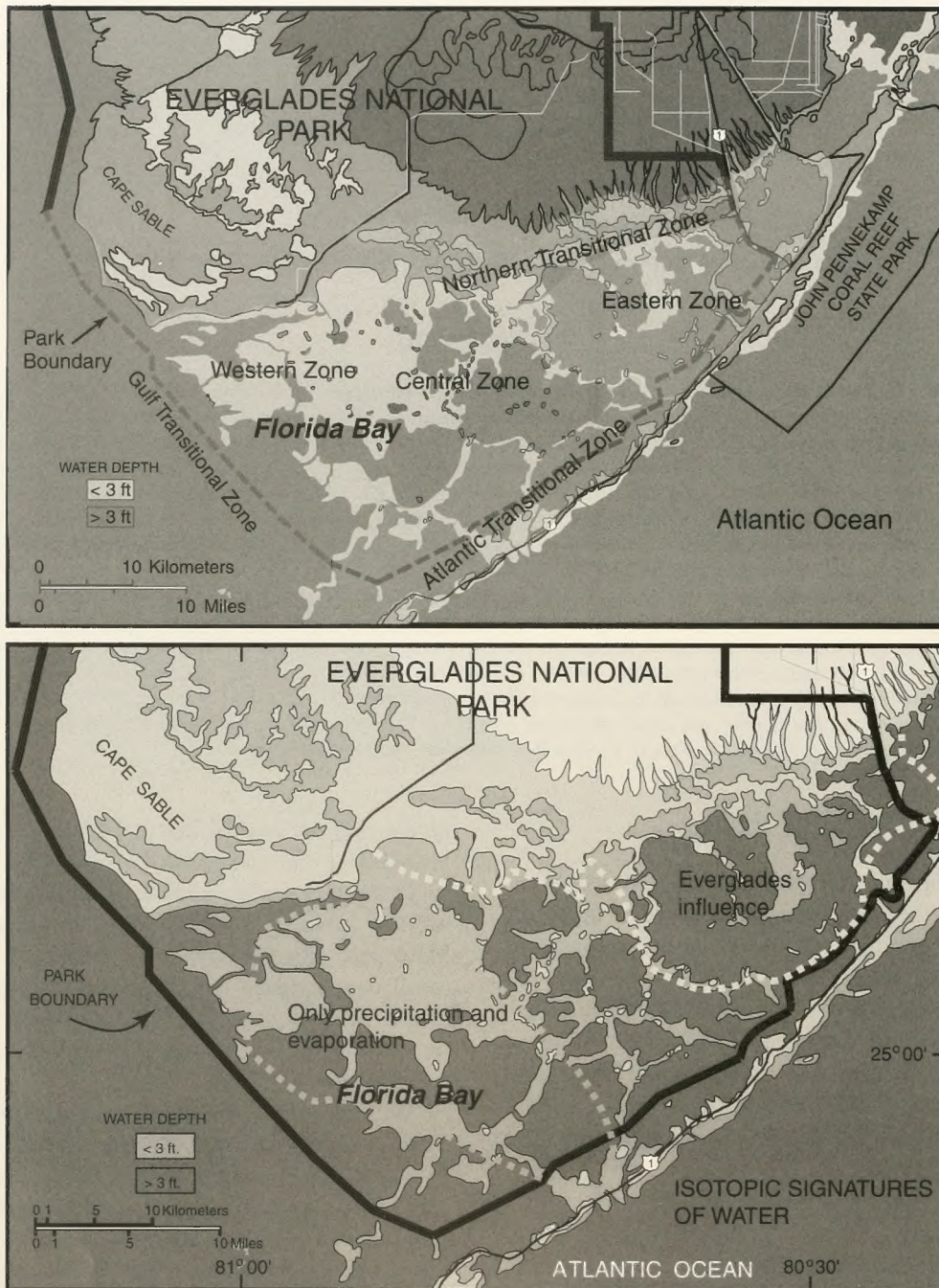
Swart *et al.* (Chapter 2) show by the isotopic signature of the water that salinity in central, western and southern (Atlantic transitional) zones of Florida Bay is influenced by direct rainfall; salinity in the northern (northern transitional) and eastern zones of Florida Bay is influenced to a large extent by runoff (Text-fig. 1).

Holmes *et al.* (Chapter 3) discuss the utility of ²¹⁰Pb in dating cores from the mud banks of Florida Bay. This technique provides age models for the last 150

years and is critical for unraveling the sequence of variability and change in Florida Bay.

In the peats of the terrestrial ecosystem and the peats of the initial transgression in the bays, radiocarbon dates provide the age framework and are reliable up until near modern time where the margin of error exceeds the age value. ²¹⁰Pb has provided reasonable age models in the uppermost part of the peats for the last century of deposition.

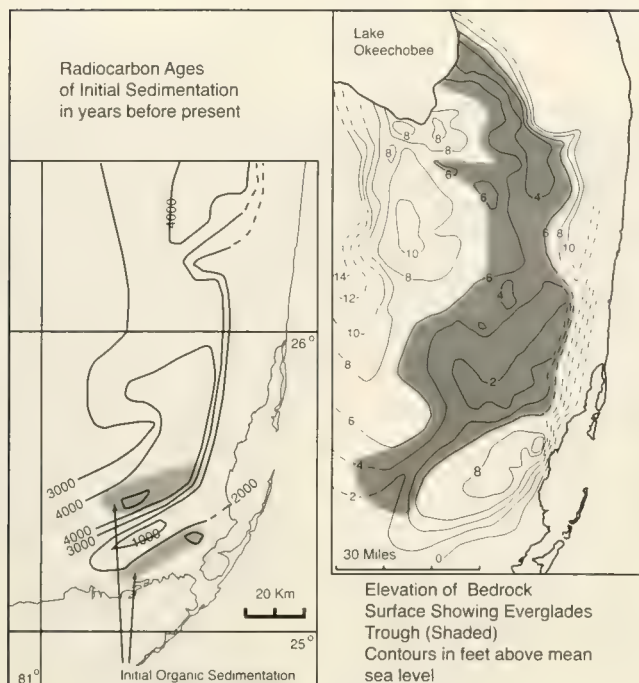
Willard *et al.* (Chapter 4) utilize modern census data from the ridge and slough and southeastern Everglades National Park along with that data collected by Riegel (1965) to develop a robust modern analogue for interpreting down-core terrestrial samples. Core samples are from the northern ridge and slough, Shark River Slough, and Taylor Slough. The core data indicate that the Everglades were generally wetter (experienced deeper water and longer hydroperiods) than today, but experienced three significant drying spells: one that correlates with the Medieval Warm Period (800–1400 AD); one that correlates with the Little Ice Age (1550–1850 AD); and one that is the present century. The present dry spell shows a progressive deterioration with shallower water and shorter hydroperiods by 1930, significant localization of the marsh in the 1950's and 1960's, and expansion of cattail marshes at nutrient-enriched sites after 1960.



Text-figure 1.—Zones of Florida Bay defining eastern, northern (Northern Transitional), central, western, and southern (Atlantic Transitional) Florida Bay and isotopic signature of the waters (derived from Swart *et al.*, this volume).

Winkler *et al.* (Chapter 5) concentrate on several cores from the brackish marshes and wet prairies of eastern Everglades National Park where marls and calcareous soils currently dominate. They provide a wealth of data from a variety of fossil groups. An interesting insight, based on the distribution of chitinous exoskeletons of cladoceran crustaceans from two cores shows a dramatic recent increase; it is commonly as-

sociated with periphyton; and implies that periphyton may also be a recent phenomenon, corresponding to nutrient and trace element increases from land use changes during the last 50 years. This suggestion needs careful documentation of the modern distribution and the distribution in many more cores before it can be substantiated. Winkler *et al.* (Chapter 5) envision Everglades peat deposition initiating about 5,000

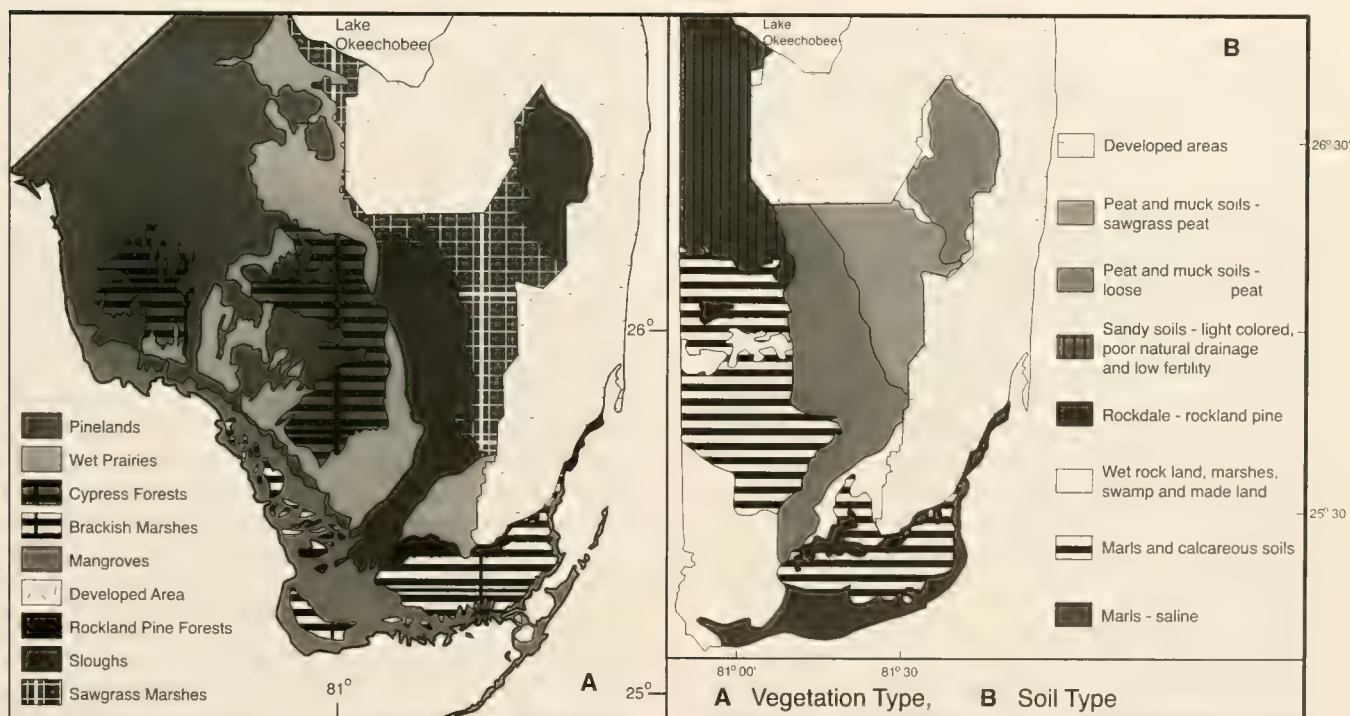


Text-figure 2.—Basal ages of initial Everglades transgressive sedimentation modified from data presented in Winkler *et al.* (this volume) and elevation of bedrock surface modified from Brooks (1984) outlining Everglades trough (shaded, elevations generally 6 ft or less above mean sea level).

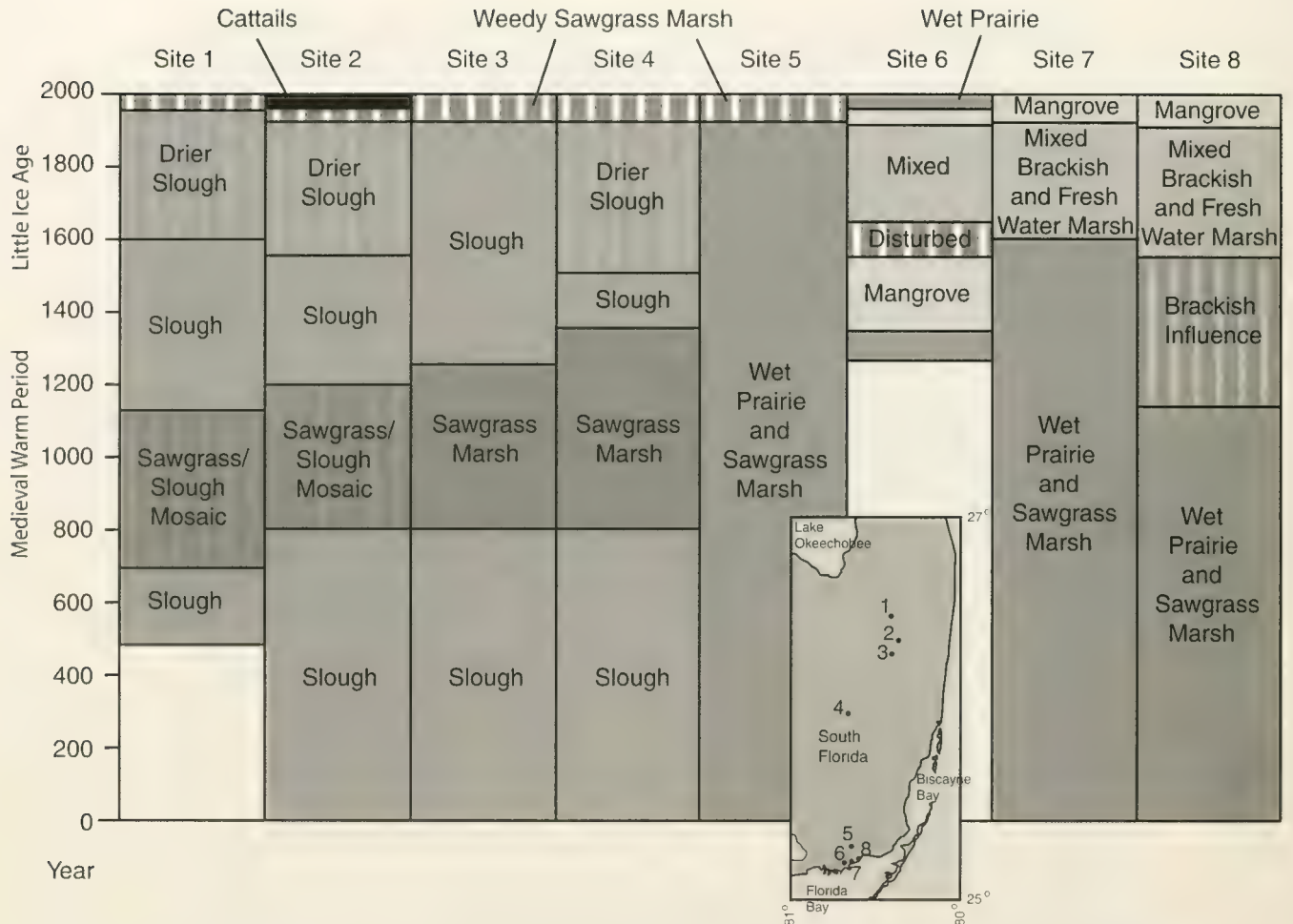
years ago by a widespread climate change; however, based on their data, it is more easily explained as part of the Holocene transgression (see below). They caution that dating at close intervals is critical to understanding the ecosystem history, yet fall prey to lack of precision when their correlation of marls as contemporaneous is not supported by their sparse age data. However, based on diatom abundances, they propose a wet period between 2,000 and 1,600 years B. P., which agrees with the wet period observed by Willard *et al.* (Chapter 4) based on pollen at the base of their sections (0 to 800 AD).

O'Neal *et al.* (Chapter 6) utilize census data from Riegel (1965) which concentrated on the western portion of Everglades National Park. Numerical analysis (cluster and multivariate analysis) characterize spatial pollen zones of the western Everglades and examine the historical record in two cores from the mangrove swamps of the same region. They document the overall late Holocene transgression and differentiate mangrove swamp communities as coastlines that first transgressed and then were stabilized.

Zarikian *et al.* (Chapter 7) show that rainfall is the dominant driving force behind long-term variability in microfaunal assemblages from one core from Oyster Bay within the mangrove forests. This environment (interior mangrove forest) generally is most susceptible to hurricane devastation and yet the core provides



Text-figure 3.—Vegetation types (A) of South Florida (modified from Willard *et al.*, this volume) and soil types (B) of parts of South Florida (modified from Willard *et al.*, 2001).



Text-figure 4.—Pollen wetland subenvironments indicated for eight peat cores from South Florida over the past 3 millennia. Locality shown in inset (modified from data in Willard *et al.*, this volume).

little correlation to hurricane events, though the authors maintain they remain an important factor. Stable isotopes from ostracode and foram tests suggest a decoupling of rainfall and freshwater flow during the 1970's for this particular location.

Huvane and Cooper (Chapter 8) show that diatoms are common to Florida Bay cores and useful in seagrass, salinity, and productivity studies.

Cronin *et al.* (chapter 9) utilizing ostracode-epiphyte distributions show that seagrass and macro-benthic algae fluctuate in abundance and coverage. They were sparse in the late 19th and early 20th centuries, dense in the 1950's and 1960's and declined in the 1970's and 1980's; but they are still more common than at the turn of the 20th century.

Brewster-Wingard *et al.* (Chapter 10) show that the molluscan faunas that occur throughout the cores basically reflect the same fauna that is present at those sites today. However, subtle fluctuations in patterns of

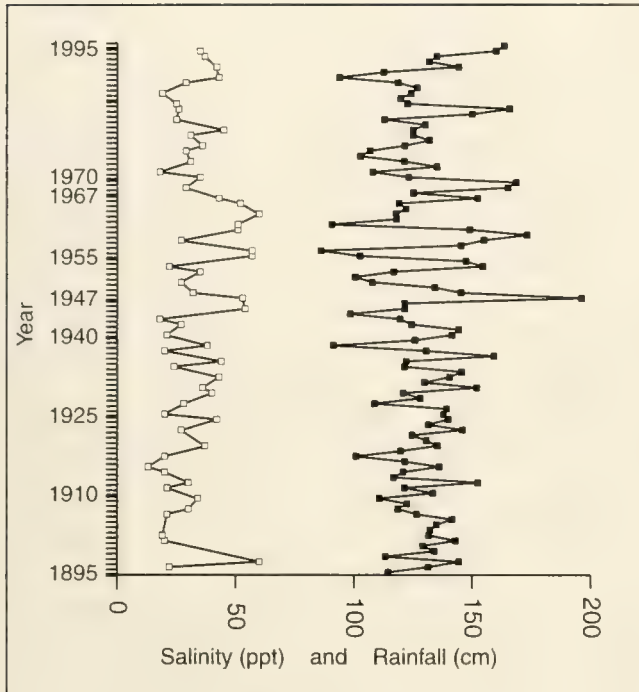
dominance and diversity track the changes in local habitat, salinity, and water quality through time.

Ishman (Chapter 11) recognizes four distinct foraminiferal assemblages in Biscayne Bay: an open-bay seagrass, an open-bay substrate, a restricted and a high productivity assemblage. The restricted assemblage represents reduced salinity, restricted circulation, and point-source fresh water input. The high productivity assemblage represents high nutrient input and is very local in the northern part of the Bay.

Dwyer and Cronin (Chapter 12) show that Mg/Ca ratios from adult ostracode shells reflect the salinity and provide a reasonable value function; they conclude that there is a strong climatic control on Florida Bay salinity.

THE EVERGLADES

Data presented in this volume suggest that the Everglades are the result of a delicate balance of sea level rise and climate (precipitation). Comparison of the age

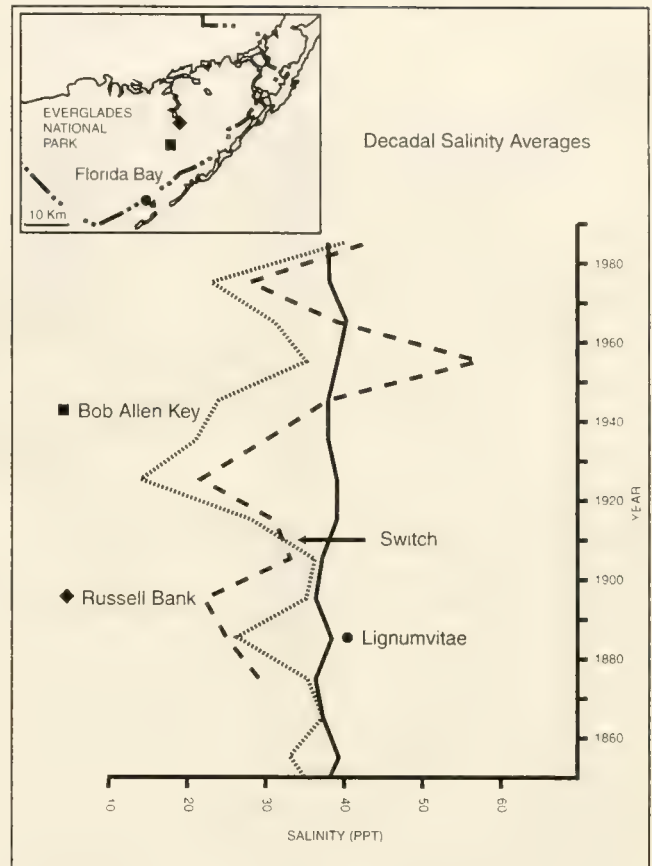


Text-figure 5.—Average annual rainfall for South Florida, in cm, compared to salinity derived from shell elemental chemistry of ostracodes from the Russell Bank Core (for location see Fig. 6, modified from Dwyer and Cronin, this volume). Notice the strong match of low rainfall years and high salinity up to 1967 and inconsistent matches following that year.

of initial sedimentation of Everglade deposits to the elevation of bedrock (Text-fig. 2) shows a direct correlation of lower elevations and earlier deposition. Clearly, the Everglades represent a growing terrestrial marsh ecosystem with rising base level driven by sea level rise. This is exactly what O'Neal *et al.* (Chapter 6) could discern from their work, documenting a transgressive sequence in the mangrove environments.

Vegetation and soil type (Text-fig. 3) distributions agree well with each other and show a direct correlation to the trough shown by lower elevation (Text-fig. 2) with the area that comprises the ridge and slough vegetation of the Everglades today.

Willard *et al.* (Chapter 4) indicate three general drying phases in the history of the Everglades summarized in Text-figure 4. These correspond to the Medieval Warm Period (800–1400 AD), the Little Ice Age (1550–1850 AD), and the present (post-1930 AD). Much evidence suggests that the Medieval Warm Period represented a period of decreased rainfall in the subtropics (see Willard *et al.*, Chapter 4); hence the reason for the drying of the Everglades. However, the explanation of the Little Ice Age is less clear. Fairbridge (1984) presents a lot of anecdotal evidence for a decrease in the rate of sea level rise or even a slight

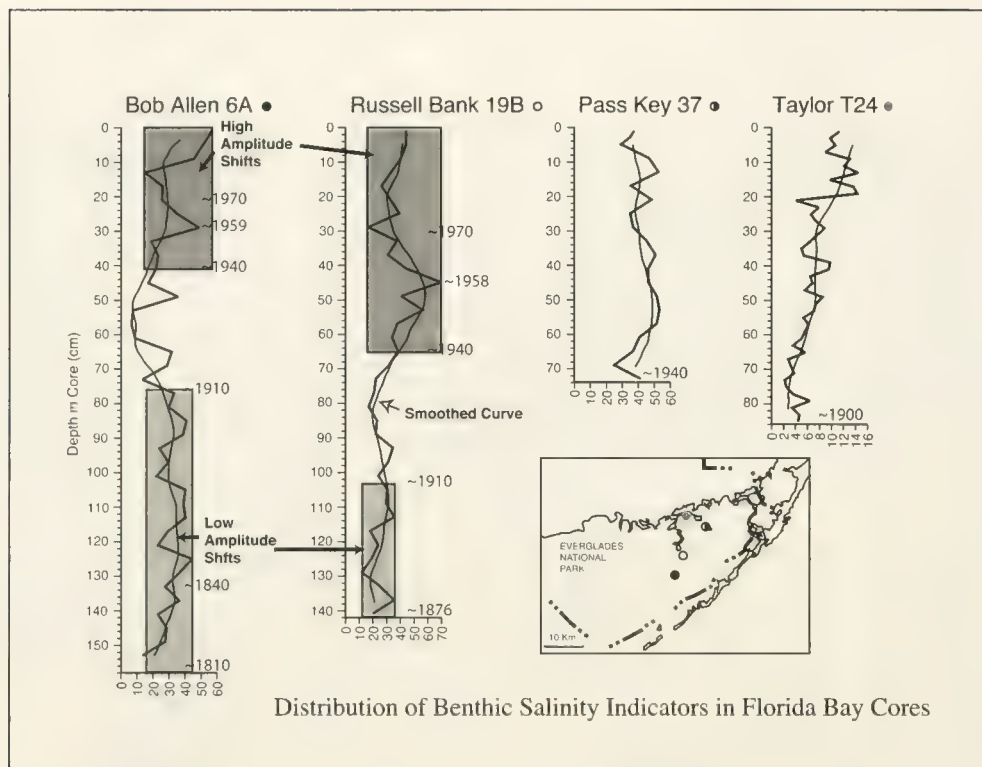


Text-figure 6.—Decadal salinity averages across Florida Bay.

fall, during the Little Ice Age. It appears that a drop in base level along with a slight decrease in the precipitation probably caused the drying conditions observed for the Little Ice Age period in the Everglades. This emphasizes the subtle interplay of base level and precipitation in maintaining deep water levels and long hydroperiods for the Everglades. Long term sea-level curves (Robbin, 1984; Toscano and Lundberg, 1998) are smoothed given the coarseness of the data compared to the fluctuating curve of Fairbridge (1984). All consistently show a decrease in the rate of sea-level rise approaching the present, which suggests a natural drying trend for the Everglades. However, the present shows a dramatic drying trend, starting around 1930 (Willard *et al.*, Chapter 4), and fragmentation after 1960 that appear to be beyond the interplay of precipitation and base level.

SALINITY IN FLORIDA BAY

Data presented in this volume and in an earlier summary by Brewster-Wingard *et al.* (1998) indicate that fossil and geochemical proxies yield fairly reliable salinity information from Florida Bay. The distribution



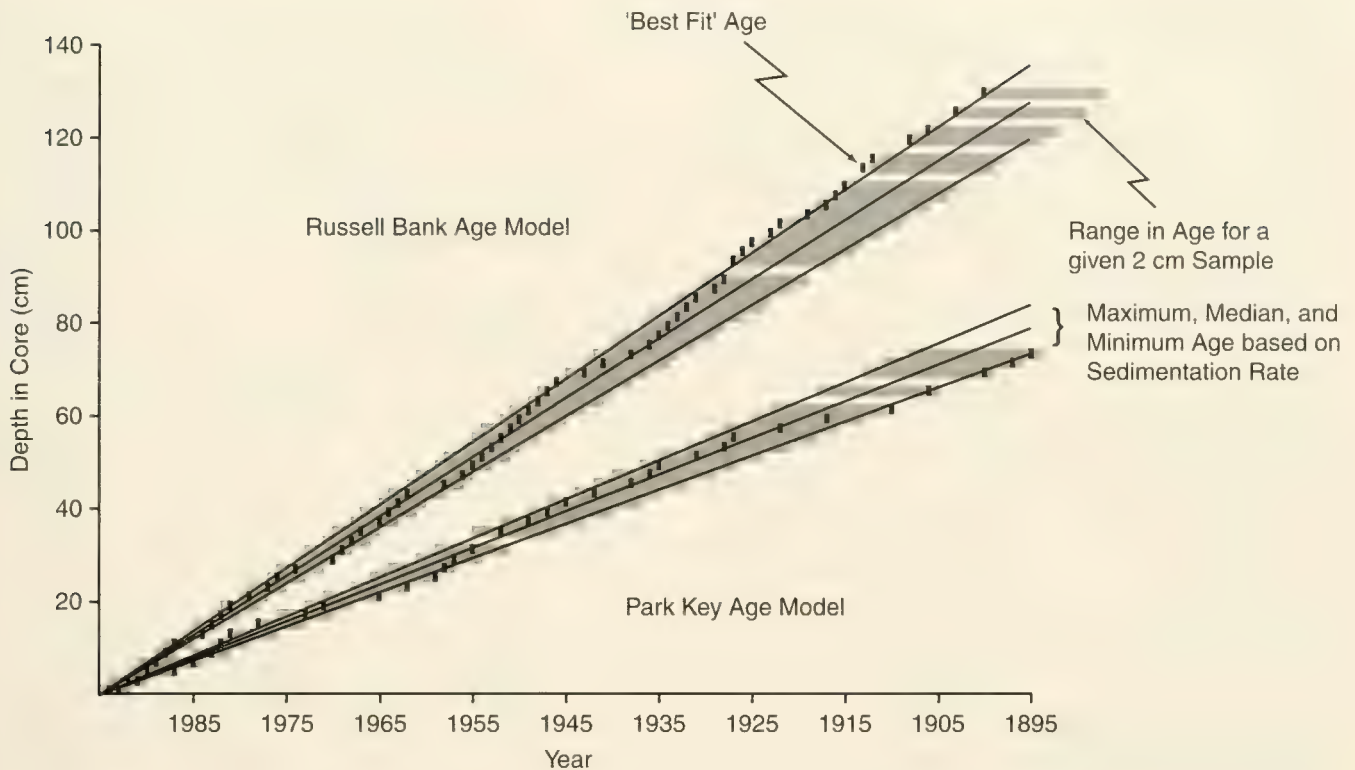
Text-figure 7.—Distribution of benthic faunal indicators of euhaline and near euhaline conditions (> 25 ppt) in four cores from Florida Bay (modified from Brewster-Wingard *et al.*, 1998).

of benthic faunal indicators (foraminifer, ostracodes, and mollusks) from four cores and the shell geochemistry of the ostracode shells from three of these cores have been analyzed. We are continuing the shell geochemistry analysis of additional cores, looking at the results in different growth stages, and looking at the elemental chemistry and carbon and oxygen isotopes of mollusk shells in an effort to evaluate the seasonal variability in salinity over the last century.

The salinity values derived from shell geochemistry are compared to the average annual rainfall for South Florida (Text-fig. 5). The salinity record is taken from 2 cm samples that average approximately 2 years/sample based on the age model which yields a sedimentation rate of 1.28 cm/year (Russell Bank Core, see Holmes *et al.*, Chapter 2). The average rainfall curve is a compilation of the available data from NOAA website (<http://www.ncdc.noaa.gov/onlineprod.drought/xmgr.html>) for the three reporting districts that makeup South Florida (the SW, the SE coast, and the Bay and Keys), averaged to one composite and covering the years 1895 to the present. Our core was taken in 1995. The rainfall pattern beginning the 19th century shows high frequency, low amplitude shifts that change to high frequency, high amplitude shifts in the late 1930s, and change again to moderate frequency,

moderate amplitude shifts for the latter part of the 20th century. The derived salinity curve matches the rainfall curve very well for the first and middle parts of the century, with high salinity peaks occurring during low rainfall years and low salinity peaks occurring in high rainfall years. This is quite remarkable, given the difference in sampling intervals. However, following 1967, a decoupling occurs, with only the lowest rainfall years matching salinity highs and moderate and high rainfall years not corresponding consistently with moderate or low salinities. Coincidentally, 1967 is the year that South Florida came under complete water control management. Recent isotopic data from Swart (Chapter 2) suggest that the salinity values in the eastern part of Florida Bay are affected directly by surface waters as those waters have an isotopic composition that reflects strong mixing with Everglades water. Therefore, rainfall is coupled to decreases in salinity directly by increased surface water flow and that flow was disrupted in the late 1960's.

Swart *et al.* (1996b) presented salinity data based on C and O isotopic studies of the growth bands in a rare large coral head in Florida Bay from *Lignumvitae* basin (inset, Text-fig. 6). The data were summarized as decadal salinity averages. I compare this to the salinity values derived from our combined fossil salinity



Text-figure 8.—Best Fit Age model for Russell Bank and Park Key.

proxies (foraminifers, ostracodes, and mollusks). Decadal averages are plotted at the midpoint of each decade (Text-fig. 6). The data for both Lignumvitae and Bob Allen Key extend back to before 1850. The Russell Bank data extends back to 1870. Prior to 1910, the three localities show a consistent gradient from fresher to more saline values from north to south in the bay. However, following 1910, Lignumvitae shows less decadal fluctuation and slightly elevated average salinities (above mean sea average) indicating more restrictive conditions. Bob Allen and Russell Bank switch; that is, though the decadal fluctuations still track each other, Bob Allen in the center of the bay becomes consistently fresher relative to Russell Bank, disrupting the gradient noted prior to 1910. Large-scale construction connecting the Keys and filling in marine passages (building the Flagler Railroad to Key West) and initial canal construction in the Everglades occurred in the first two decades of the 20th century. These activities may have directly affected the subtle changes seen in the salinity patterns of the Bay.

The salinity values derived from faunal (foraminifer, mollusk, and ostracode) proxies for our first four Florida Bay cores are shown in Text-figure 7. These are plotted against depth in core with the age model highlighted in bold. The values for the longer cores (Bob Allen and Russell Bank) show low amplitude shifts in

salinity prior to 1910 and high amplitude shifts in salinity after about 1940, agreeing with the curve developed from shell geochemistry for Russell Bank. These faunal derivations are too coarse to comment on the frequency of salinity shifts. The overall trend indicated by these benthic faunal indicators is that most of the bay seems to have experienced a slight increase in salinity values over the last century and specifically in last 30 years (post-1970).

IMPLICATIONS FOR RESTORATION

Comparison of the average annual rainfall of South Florida (Text-fig. 5) to the pollen assemblage data which is summarized in Text-figure 4 shows that broad-scale vegetational changes in the Everglades wetlands began by 1930, indicating shallower water depths and shorter hydroperiods, even though regional precipitation increased concomitantly. Further, more localized changes occurred after 1960. Thus, restoration goals of achieving pre-1960 hydrologic regimes are aimed at an already disrupted system; a more “natural” restoration target would be the 19th century Everglades, consisting of slough subenvironments which had been stable for the past few centuries. Recent land-use changes have resulted in localized rather than system-wide ecosystem responses, at least in part because of the fragmentation of the wetland. This artificially

induced ecological heterogeneity makes prediction of future wetland responses to climatic changes problematic.

Faunally and chemically derived salinity curves for Florida Bay show that salinity values are directly related to rainfall and surface water flow for the eastern half of the bay. However, following 1967, there is a decoupling of salinity response to rainfall amount and surface water flow. More subtle trends show that the annual average salinity of the bay has increased slightly during the 20th century and that the general pattern of fresher to more saline water across the eastern bay has been disrupted after the turn of the century. These trends in the salinity values of the bay are related to the disruption of both fresh-water and marine-water delivery to the system that began shortly after the turn of the century and culminated in total water-control management in 1967. Recent water practices of releasing fresh water into Taylor Slough appear to have reestablished at least a normal gradient in salinity over the past 5 years, based on our modern monitoring data (post-coring).

Long-term data provided by faunal, floral and biogeochemical analysis provide essential information to establish restoration targets for the South Florida ecosystem. These data clearly indicate that a more open water delivery system is necessary to provide eastern Florida Bay with more fresh water and the terrestrial Everglades with less restricted flow and deeper water during wet cycles, thus reestablishing more natural cycles of change.

PREDICTING SALINITY IN FLORIDA BAY

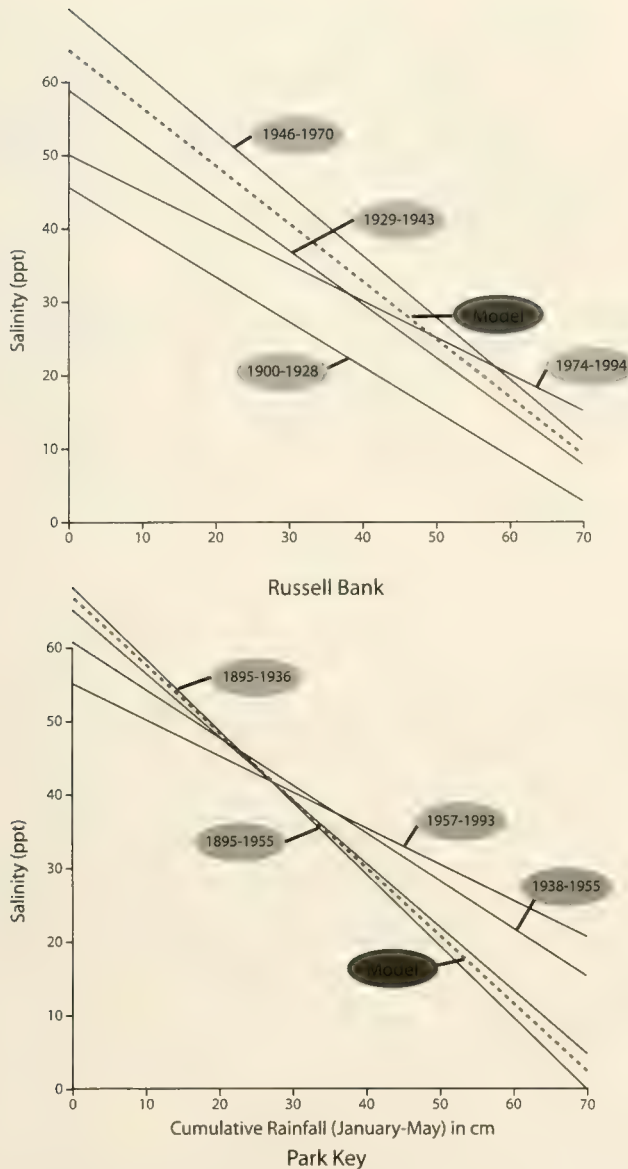
The chemical proxy data from Florida Bay cores allow us to develop predictive formulas for establishing an anticipated salinity for a given rainfall record that should help us test success in recoupling rainfall and surface water flow. It also allows us to "retune" the age model provided by Holmes *et al.* (Chapter 3).

Biotic and chemical proxies for salinity in Florida Bay show that salinity values for the last century are strongly correlated with climate, specifically, rainfall (Brewster-Wingard and others, 1998; Cronin and others, 1998). Elemental chemistry of ostracode shells provides a methodology to discern salinity values of the past (Dwyer and Cronin, 1999). Adult tests of the ostracode *Loxoconcha matagordensis* are grown essentially instantaneously in the late Spring and early Summer. Salinity values derived from adult *Loxoconcha matagordensis*, generally grown between May and July, each year serve as proxies for June salinities. Because *Loxoconcha matagordensis* growth shows a very tight normal distribution, population studies from one sample should provide us with data on salinity

Table 1.—Best Fit Model data for year, salinity (in parts per thousand, ppt), and cumulative January–May rainfall (in cm).

Russell Bank			Park Key		
Year	Salinity	Rainfall	Year	Salinity	Rainfall
1900	21	45.30	1895	31	33.46
1903	27	39.88	1897	30	30.80
1906	22	42.71	1900	27	45.30
1912	20	41.50	1906	20	42.71
1913	19	35.54	1910	58	23.60
1915	21	42.59	1917	60	17.56
1916	30	26.93	1922	38	29.52
1917	34	17.56	1927	38	21.74
1919	21	43.67	1928	29	37.05
1922	30	29.52	1931	26	50.62
1923	20	35.61	1935	47	21.07
1927	37	21.74	1936	27	45.99
1928	27	37.05	1938	40	19.03
1929	42	25.05	1942	31	45.26
1931	20	50.62	1945	53	13.68
1932	28	41.44	1947	34	43.36
1933	40	29.49	1949	56	21.67
1934	28	45.75	1952	35	28.06
1935	43	21.07	1955	51	18.84
1936	24	45.99	1957	38	51.61
1938	44	19.03	1958	33	64.36
1941	20	53.94	1959	27	41.65
1943	38	25.82	1962	60	20.67
1947	27	43.36	1966	35	42.40
1949	54	21.67	1971	49	16.33
1950	53	21.08	1973	36	27.60
1953	35	31.50	1978	25	41.01
1954	22	47.26	1981	51	20.05
1955	57	18.84	1982	34	52.45
1956	57	18.83	1983	32	67.63
1958	27	64.36	1985	45	28.03
1962	51	20.67	1987	33	38.32
1963	51	27.75	1991	28	48.61
1964	60	29.87	1993	26	50.50
1965	52	21.99			
1967	43	19.43			
1968	29	46.33			
1969	35	43.01			
1970	18	51.28			
1974	31	20.40			
1976	29	37.90			
1977	36	36.60			
1979	31	40.62			
1981	45	20.05			
1982	25	52.45			
1984	25	45.80			
1987	19	38.32			
1988	29	32.83			
1989	43	22.17			
1990	42	31.73			
1992	37	25.71			
1994	35	42.59			

changes occurring at the beginning of the rainy season (usually June). Russell Bank has a long record and relatively abundant *Loxoconcha matagordensis*. Park Key has a relatively short record but also has relatively



Text-figure 9.—Regression trend lines for data points listed in Table 1.

abundant *Loxoconcha matagordensis*. Biotic indicators were analyzed from every other 2 cm sample and elemental chemistry of the ostracodes was performed from every sample. The calculated sedimentation rate of the Russell Bank core is $1.28 \text{ cm} \pm 0.07$ (Holmes *et al.*, Chapter 3), so our sampling represents approximately every 1.5 to 2 years. The calculated sedimentation rate of the Park Key core is $0.78 \text{ cm} \pm 0.5$ (Holmes *et al.*, Chapter 3), so our sampling represents approximately every 2.5 years.

ASSUMPTIONS AND VALUES FOR THE MODEL

January–May rainfall.—Monthly rainfall information is available from NOAA website ([www.ncdc.](http://www.ncdc.noaa.gov/onlineprod.drought.xmgr.html)

Table 2.—Linear equations and R^2 values for regression trend lines for all points, natural clusters, and model linear equation for site at present for 'natural' restoration.

	Russell Bank	Park Key
All Points	$y = -0.78x + 60.08$ $R^2 = 0.5508$	$y = -0.57x + 57.86$ $R^2 = 0.5278$
1900–1922	$y = -0.62x + 46.60$ $R^2 = 0.6541$	
1895–1936		$y = -0.97x + 68.25$ $R^2 = 0.7027$
1929–1943	$y = -0.73x + 58.83$ $R^2 = 0.9683$	
1895–1955		$y = -0.86x + 65.24$ $R^2 = 0.6882$
1946–1970	$y = -0.85x + 69.94$ $R^2 = 0.7414$	
1938–1955		$y = -0.66x + 60.75$ $R^2 = 0.6466$
1974–1994	$y = -0.50x + 49.98$ $R^2 = 0.4253$	
1957–1993		$y = -0.45x + 55.27$ $R^2 = 0.4907$
Model	$y = -0.79x + 64.38$	$y = -0.92x + 66.74$

noaa.gov/onlineprod.drought.xmgr.html) dating back to 1895. The eastern portion of Florida Bay is influenced by rainfall and surface run-off. To compare rainfall to salinity values on a monthly basis, averages of the three southern districts (southwest (Everglades), southeast coast, and Bay and Keys) were taken because rainfall to all three may influence salinity in Florida Bay. Because the focus is June salinity, rainfall from the five preceding months was examined to establish a relationship. During El Niño years, high winter rainfall is usually recorded in January; therefore, January rainfall is included in the data set to indicate the occurrence of these events. This methodology appears to combine the affects of both direct rainfall and surface water runoff. The salinities derived from the cores do not match well with direct rainfall for the months of May, June, and July, and imply that surface water flow has a strong influence on the salinity at these sites.

June salinities.—Mg/Ca derived salinities from the ostracode *Loxoconcha matagordensis* from Russell Bank Core and Park Key Core as discussed above and derived from the analyses listed in Dwyer and Cronin (this volume). Wardlaw and Brewster-Wingard (2000) have shown significant correlation between the January–May rainfall and derived salinities for the eastern portion of the Bay. Here, I have taken the age model of Holmes *et al.* (Chapter 3, this volume) and fine tuned it (Text-fig. 8) matching better rainfall to salinity values within or close to within the allowable ages given the age model and sampling interval (see Table 1 for all data).

Results.—The relationship between January–May average rainfall for South Florida and June “ostracode” salinities can be expressed as a series of simple linear equations of negative correlation (Text-fig. 9) and provides us with a predictive value. The relationships for all derived values and relationships that cluster in age groups are shown in Table 2.

The lessening of slope appears to indicate disruption or decoupling of the natural system. At Park Key, this appears as early as the 1930's. At Russell Bank, it appears in the seventies. The correlation value (R^2) also decreases greatly at major disruption. Though Park Key appears disrupted early in the century, its impact appears minor in that the trend line for all data 1895–1955 is still very close to that before disruption. A model for prediction of salinity can be derived between these two trend lines (Text-fig. 9).

Russell Bank shows a progressive change in slight increase in slope and rising in overall salinity through most of the century. Rainfall patterns are changing from high amplitude, high frequency fluctuations to more moderate amplitudes and frequencies and a model for prediction can be derived between trends of 1929–1943 and 1946–1970, suggesting a slight lessening of overall salinity for this site.

The slope of the trend line decreases as a function of distance from surface water source and with a few additional cores could be mathematically modeled.

In addition, the interplay of rainfall versus surface water flow on salinity can be addressed by looking at the biology of the ostracodes more closely and developing chemical proxies from longer-lived taxa such as molluscs that can yield multi-year records of nearly continuous carbonate secretion.

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CHAPTER 2

THE RELATIONSHIP BETWEEN STABLE ISOTOPIC VARIATIONS (O, H, and C) AND SALINITY IN WATERS AND CORALS FROM ENVIRONMENTS IN SOUTH FLORIDA: IMPLICATIONS FOR READING THE PALEOENVIRONMENTAL RECORD

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ABSTRACT

The oxygen isotopic composition of calcareous material secreted by organisms is often used for the reconstruction of salinity values in past environments. Implicit in this reconstruction is the assumption of a constant relationship between salinity and the $\delta^{18}\text{O}$ value of water. In this paper, we demonstrate through the analysis of water samples collected from several estuaries situated adjacent to the Florida mainland that varying relationships exist between these two parameters depending upon the extent of evaporation experienced by the freshwater which influences the salinity. We further show that these relationships are translated into the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of corals growing in these environments. Water samples collected from Florida Bay, Whitewater Bay, and the Ten Thousand Island area between October 1993 and December 1998 show a range of correlations between the $\delta^{18}\text{O}$ of the water and salinity. These varying correlations arise because while water from the Everglades possesses a low salinity it has a relatively positive $\delta^{18}\text{O}$ value. In contrast, precipitation has a more negative $\delta^{18}\text{O}$ value. Consequently, areas in which the salinity is significantly influenced by freshwater derived from the Everglades tend to have different $\delta^{18}\text{O}$ to salinity relationships compared to regions where salinity variations are caused solely by inputs of precipitation. These variations must be recognized if one is to use proxy indicators of salinity such as the $\delta^{18}\text{O}$ value of skeletal carbonates to accurately reconstruct past salinity records.

The $\delta^{13}\text{C}$ of estuarine waters is related to both the input of isotopically depleted runoff from the Everglades and the local remineralization of organic material. Areas far removed from Everglades runoff, where variations in salinity resulted from input of precipitation, show little relationships between salinity and $\delta^{13}\text{C}$ because $\delta^{13}\text{C}$ variations arise from the local remineralization of organic material. In contrast, areas closer to the Everglades show stronger relationships between salinity and $\delta^{13}\text{C}$. These relationships are manifested in the isotopic composition of the coral skeleton as an absence of correlation between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in more marine areas compared to areas more directly influenced by runoff.

INTRODUCTION

The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ values of calcareous organisms (ostracods, foraminifera, molluscs, and corals) have been used in the South Florida environment to ascertain changes in past environmental conditions, in particular salinity (Swart *et al.*, 1996; Swart *et al.*, 1999; Halley and Roulier, 1999; Nelsen *et al.*, 2000). The results of these studies indicate a change in salinity patterns commencing in Florida Bay as early as 1900. A concurrent shift in the $\delta^{13}\text{C}$ in both corals and molluscs suggest that a reduction in the hydrodynamic circulation of Florida Bay may be responsible for the observed changes in salinity. Construction of the Overseas Railway from Miami to Key West from 1906–1914, followed by water management practices which diverted the natural flow of water from the Everglades into Florida Bay have been suggested as possible causes for the reduced circulation within Florida Bay (Smith *et al.*, 1989; Swart *et al.*, 1996, 1999).

Anthropogenic changes in South Florida occurred synchronously with climatic variability. Regional droughts have been recorded in every decade from 1950 to 1990 resulting in salinity exceeding 50 in the central portions of Florida Bay (Fourqurean and Robblee, 1999; Fourqurean *et al.* 1992). In contrast, the 1997 El Niño, termed the “El Niño of the Century” produced above average rainfall during the winter dry season in South Florida. Decoupling these natural climatic conditions from anthropogenic conditions is important in deciphering the paleoenvironmental record.

This paper examines the associations between salinity, precipitation, and the $\delta^{18}\text{O}$, δD , and $\delta^{13}\text{C}$ of surface waters from ‘fresh’, estuarine, and marine environments of South Florida and relates these data to the interpretation of the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ record of two corals growing in Florida Bay. In order to study these relationships, we have conducted a temporal and spatial investigation of the $\delta^{18}\text{O}$, δD , and $\delta^{13}\text{C}$ composition of

waters from the Everglades, Florida Bay, Whitewater Bay, and the Ten Thousand Islands areas. These data were then correlated with salinity measurements made on the same samples (Boyer *et al.*, 1999).

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BACKGROUND

HYDROLOGICAL SYSTEM IN SOUTH FLORIDA

South Florida experiences a subtropical climate with a hot, wet season during the summer (mid-May–October), and a mild, dry season during the winter (November–mid-May). Annual precipitation is approximately 130 to 150 cm across the region, with approximately 70% received during the summer wet season (Leach *et al.*, 1972). The seasonality of precipitation and evaporation causes a seasonal fluctuation in surface water levels in South Florida. Water levels rise during the summer rainy season, with highest levels commonly observed in September and October. During the winter dry season, water levels decline slowly. Surface water can be absent from many areas of the Everglades at the end of the dry season (April and May) as evapotranspiration exceeds rainfall (Kushlan, 1990).

The Everglades depression extends southward from Lake Okeechobee to Florida Bay and is bounded to the east by Pleistocene limestones and quartz sands of the Atlantic Coastal Ridge and to the west by exposed Pliocene limestones of the Big Cypress Ridge. Holocene freshwater peats and marls partially fill the Everglades trough, decreasing in thickness southward from 4 m at the southern end of Lake Okeechobee to 0.7 m along the coastline of Florida Bay (Kushlan, 1990). Under natural, pre-development conditions, most surface water flowed southward in the Everglades from Lake Okeechobee to the Gulf of Mexico via the Shark River Slough (Fennema *et al.*, 1994). A smaller drainage area, Taylor Slough, discharged locally derived freshwater into Florida Bay. Beginning in the late 1800s and throughout the 1900s, a complex network of canals, levees, pump stations, and im-

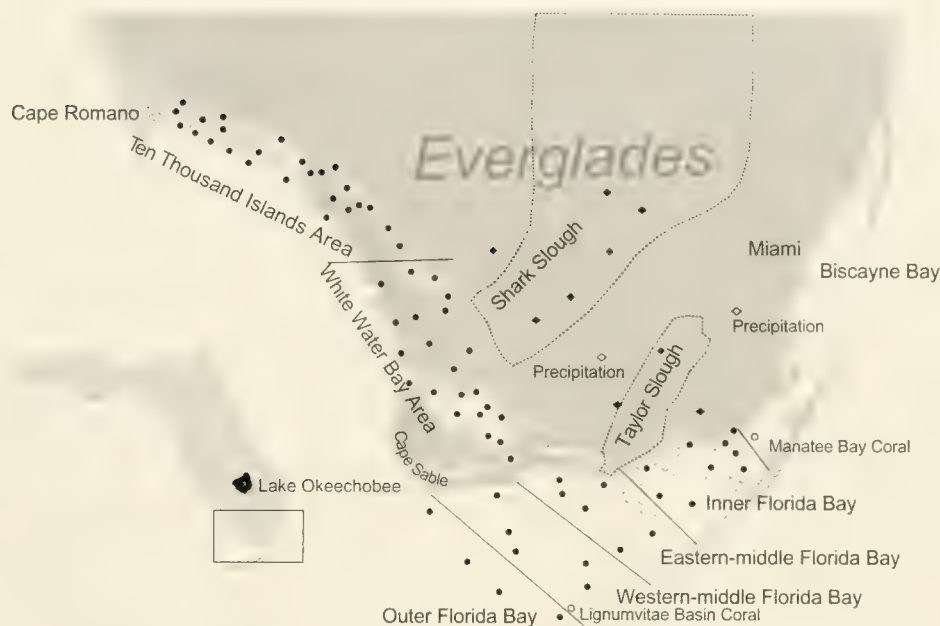
poundment areas were constructed throughout South Florida in an effort to manage water levels and flow throughout the region. Because of the resultant impoundment of water in what are known as conservation areas, evaporation is high, with estimates of rainfall lost to evapotranspiration being as high as 70% to 95% (Leach *et al.*, 1972). This decreased surface water flow from Lake Okeechobee, through the Everglades to the marine systems of the Gulf of Mexico and Florida Bay, and increased drainage eastward toward Biscayne Bay (Fennema *et al.*, 1994).

Marine environments that bound the southern peninsula of Florida include the Gulf of Mexico to the west, Biscayne Bay to the east, and Florida Bay to the south. The west coast from Cape Romano in the north to Cape Sable in the south, is characterized by mangrove swamps, tidal channels and small bays. The northern section contains numerous mangrove islands separated by tidal channels with strong currents and is referred to as the Ten Thousand Islands (TTI) area. South of the TTI, tidal currents are more sluggish and freshwater runoff from the Big Cypress Swamp and the Everglades is transported to the Gulf of Mexico by numerous streams (Davis, 1997).

Florida Bay is a large (2,000 km²) triangular shaped estuary lying between the Southern Peninsula of Florida and the Florida Keys. Florida Bay is relatively shallow and underlain by a complex system of Holocene carbonate mud-banks that subdivide Florida Bay into smaller basins. Water in Florida Bay is a mixture of precipitation, freshwater runoff from the Everglades, and seawater from the Gulf of Mexico and the Florida Straits. These sources combined with evaporation results in salinity variations from 4 to 50 (Nuttle *et al.*, 2000).

STABLE ISOTOPES

The major influence on variations in the ratio of ¹⁸O to ¹⁶O and D to H in the water cycle occurs during the processes of evaporation and precipitation (Craig and Gordon, 1965). During evaporation, the concentrations of ¹⁸O and D are reduced in the water vapor while these same species are enriched in the condensate. As a consequence, restricted bodies of water become enriched in the heavier isotopes during evaporation while precipitation is typically enriched in ¹⁶O and H. Precipitation throughout the world has been measured by the International Atomic Energy Authority (IAEA) and this data set shows that precipitation values become increasingly depleted towards the north and south poles (Rozanski *et al.*, 1993). In South Florida the IAEA data estimates that rainfall should have a $\delta^{18}\text{O}$ value between -2 and -4‰ . The behavior of the isotopic composition of water during evaporation and



Text-figure 1.—Location map of water sampling stations within each geographic region.

precipitation can be modeled using the Rayleigh Distillation Equation. However, the maximum amount of enrichment in the heavier isotope that can be experienced by an evaporating water body is limited by subsequent exchange between the atmospheric moisture and the water body. The resulting isotopic composition that can be attained during evaporation is a function of the relative humidity, temperature of evaporation, and the isotopic composition of the atmosphere. The principals which govern the isotopic composition of such water bodies have been well studied and for further discussion the reader is referred to Gat (1981) and Gonfiantini (1986). For an environment such as South Florida where the mean relative humidity is 75%, the maximum $\delta^{18}\text{O}$ and δD that can be attained by the water body undergoing evaporation are approximately +4‰ and +42‰, respectively. Although the δD vs. $\delta^{18}\text{O}$ of most precipitation throughout the world falls along a line known as the meteoric water line (MWL) (Craig and Gordon, 1965), data from evaporating water basins, when plotted on a similar diagram, fall on lines which deviate from the MWL depending upon the relative humidity. For example, environments with high relative humidity fall close to the MWL with a slope of 8, while waters evaporated into an environment with a lower relative humidity will plot on a line with a slope significantly less than 8 (Gonfiantini, 1986).

The dissolved inorganic carbon (DIC) pool is composed of CO_2 , HCO_3^- , and CO_3^{2-} . In waters of pH

between 7 and 9, the DIC is dominated by HCO_3^- . Although there is a large fractionation factor between CO_2 and HCO_3^- ($\epsilon = 8\text{‰}$), the measured isotopic composition of the DIC reflects that of the HCO_3^- fraction. Hence when CO_2 is added to water the isotopic composition of the HCO_3^- will be approximately 8‰ heavier than that of the CO_2 .

The $\delta^{13}\text{C}$ of the DIC is governed by the input of respiratory carbon delivered to the system through the respiration of organic material and the consumption of CO_2 through the process of photosynthesis. As organic material contains less ^{13}C than DIC which is in equilibrium with the atmosphere, addition of oxidized material will cause the $\delta^{13}\text{C}$ of the DIC to become enriched in the lighter isotope of C (^{12}C). Terrestrial organic materials tend to have more negative $\delta^{13}\text{C}$ values than marine material, and therefore waters derived from terrestrial sources associated with the oxidation of organic material often have more negative isotopic signatures than waters derived from marine sources. In a relatively closed system, the utilization of CO_2 in the process of photosynthesis can cause the residual pool of carbon in an environment to become enriched in ^{13}C . Hence algal blooms for example could lead to more positive DIC $\delta^{13}\text{C}$ values.

METHODS

WATER SAMPLE COLLECTION

Surface water samples were collected monthly since October 1993 in Florida Bay (Text-fig. 1). In October

1996 and February 1997, additional stations were added first in Whitewater Bay and subsequently in the Ten Thousand Islands area. Sampling for $\delta^{18}\text{O}$ at nine sites in the Everglades was initiated in August 1996. All water samples were collected in the field, filtered through a $0.45\ \mu\text{m}$ filter to remove carbonate and other particles, and treated with a small amount of HgCl_2 to suppress biological activity. In the laboratory, the samples were transferred to serum bottles and capped to exclude as much of the air space in the bottle as possible. Repeated analyses of samples stored in this manner have not detected appreciable change in the isotopic composition over periods of up to five years.

Salinity was measured at each surface water sampling location (except for the Everglades locations) by Florida International University/Southeastern Environmental Research Program (FIU/SERP). A summary of these data has been published by Boyer *et al.* (1999). Automated water salinity monitors were deployed at three locations in Florida Bay: Lignumvitae Basin, East Key and Manatee Bay. Hourly salinity data were obtained using a Hydrolab Datasonde 3 between 1995 and 1998 in Lignumvitae Basin. Similar data from East Key and Manatee Bay were collected over shorter time periods. Each instrument was serviced at 6 to 8 week intervals. Servicing consisted of cleaning organisms which encrusted the housing and sensors, replacing batteries, and calibrating the instrument for salinity. Drift in the instrument within a given sampling period was corrected by measuring the salinity and temperature with the instrument at the beginning and end of each deployment period and assuming a linear instrument drift during the deployment period.

Precipitation samples were collected between August 1997 and December 1998 from two locations on the South Florida mainland. At the Redlands site, located southwest of Miami, precipitation was collected in a bottle equipped with funnel and tube. On a daily basis, the contents of the bottle were transferred to another bottle that was kept indoors and capped to form a bi-weekly to monthly composited sample. Daily amounts of precipitation were recorded with a standard wedge gage. Precipitation was also collected behind the Iori Building within Everglades National Park from December 1997 through December 1998, using an Aerochemetrics Wet/Dry collector. This collector consisted of two buckets, one to collect dry deposition and the other to collect wet deposition. The instrument was equipped with a heated sensor that when wet activated a mechanical arm that moved a cover from the wet collection bucket to the dry collection bucket, thereby exposing the wet collection bucket to rainfall. The heated sensor allowed for evaporation of rainfall that collected on it, and once dry, the mechanical arm

was moved again to cover the wet collection bucket to prevent evaporation of the rainfall sample. Amount of precipitation was measured directly from the wet collection bucket using a ruler.

CARBON ISOTOPIC COMPOSITION OF DISSOLVED INORGANIC CARBON (DIC)

The $\delta^{13}\text{C}$ of waters was measured using two methods.

Method 1: The $\delta^{13}\text{C}$ of the DIC for samples collected early in the project were determined by acidification under vacuum. Prior to analysis a sample (5 cc) was withdrawn from the serum bottle through a septum. The displaced volume of water was replaced by nitrogen gas. To acidify the sample it was injected into a sealed vessel through a septum which contained 0.5 cc of H_3PO_4 . The sample and acid were then removed from the vacuum line and thoroughly shaken. The vessel was then reattached to the vacuum line and after evacuation the CO_2 produced was allowed to expand through a water trap and then frozen with liquid nitrogen into a vacuum vessel. The vessel was subsequently attached to a stable isotope mass spectrometer (Finnigan-MAT 251) and the ratios of $^{13}\text{C}/^{12}\text{C}$ and $^{18}\text{O}/^{16}\text{O}$ determined in a similar manner to the CO_2 produced from the acidification of carbonate. Standards were made by dissolving NaHCO_3 of known $\delta^{13}\text{C}$ in 18.3 Mohm water to make a 4 mM solution. Standardization is relative to PDB and data are reported in conventional δ units. Reproducibility was determined by replicate analysis of the same sample and has been measured at $\pm 0.1\text{‰}$.

Method 2: The $\delta^{13}\text{C}$ of the DIC for samples collected during the latter stages of the project was determined using a continuous flow mass spectrometer. In this technique a vial with a septum containing 0.5 cc of ortho-phosphoric acid was evacuated. Two-cc of the sample was injected into the vial and thoroughly shaken. The sample was then placed along with other samples and standards in an autosampler (Gilssen) attached to a continuous flow isotope ratio mass spectrometer (Europa 20–20). Each sample in turn was purged by helium and the water removed using magnesium perchlorate. The CO_2 produced by the reaction of the acid with the dissolved inorganic carbon (DIC) was passed through a packed GC column (75°C) and then analyzed using the mass spectrometer. In this method up to 200 samples can be processed in one batch. The precision of this method is approximately the same as in the acidification under vacuum method ($\pm 0.1\text{‰}$).

OXYGEN ISOTOPIC COMPOSITION OF WATERS

The $\delta^{18}\text{O}$ of water was determined using the Epstein and Mayeda (1953) method of equilibration. Two adaptations of this method were used.

Method 1: In this technique, 1 cm³ of sample was placed in a vacuum vessel and all air removed through a process of freezing, pumping and thawing. After all air was removed, each flask was flooded in turn by 1 atm of CO₂ and the flask sealed. The water and the carbon dioxide were then allowed to equilibrate at 40°C overnight. In this process the oxygen in the water isotopically exchanged with the CO₂. The CO₂ then attained an isotopic composition representative of the water, although offset through a fractionation factor. In each run 14 samples and 2 standards were equilibrated with CO₂. Standards are related to V-SMOW through simultaneous equilibration with samples of V-SMOW distributed by the National Bureau of Standards (NBS). Reproducibility was determined by replicate analysis of the same sample and has been measured at $\pm 0.1\text{‰}$.

Method 2: In this method the entire process including the flushing of the samples with CO₂, equilibration, and extraction was handled automatically. The process was controlled by a computer interfaced to a mass spectrometer (Europa GEO) and an equilibration unit (Europa WES). In each experiment, 0.5 cc of sample was placed in a small serum vial with a septum top. These samples were flushed with CO₂ at atmospheric pressure and allowed to equilibrate for 12 hours at 35°C. The CO₂ was then extracted through a cryogenic water trap and the isotopic composition determined using a mass spectrometer. A series of 59 specimens (including samples and standards) was analyzed in a 12 hour period. The reproducibility was approximately 0.08‰.

HYDROGEN ISOTOPIC COMPOSITION OF WATERS

The δD of the water was determined using two methods. Initial samples were analyzed using the first method described for each of the elements. Later samples, 1995 to the present, were analyzed using the second method. In both methods, data are reported relative to V-SMOW.

Method 1: The first method utilized the reduction of H₂O to H₂ gas using uranium at 800°C (Friedman, 1953). The hydrogen gas was then analyzed using a stable isotope mass spectrometer (Finnigan MAT 251).

Method 2: The second method used an equilibration technique between H₂ gas and H₂O in the presence of a platinum catalyst (Hokko beads) (Coplen *et al.*, 1991). This method was used in conjunction with the second method of determining the $\delta^{18}\text{O}$ of water using

the GEO and WES. In this method the same samples which were used for the determination of the $\delta^{18}\text{O}$ were flushed with H₂. The equilibration between H₂ and H₂O occurred in a period of 30 minutes, allowing for analysis of the first equilibrated samples immediately following flushing of the last sample H₂. Precision of this method determined by replicate analyses of the standards within each run is approximately 1.5‰.

CORALS

A specimen of *Solenastrea bournoni* was cored in Lignumvitae Basin of Florida Bay in 1986 and 1993. Isotopic analyses from this specimen were reported by Swart *et al.* (1996, 1999). In 1996, a specimen of *Solenastrea hyades* was collected from Barnes Sound, near the mouth of Manatee Bay in northeast Florida Bay.

Coral cores were sliced into sections parallel to the axis of coral growth. Core sections were then subjected to X-radiography to facilitate the construction of annual coral chronologies. Skeletal coral carbonate was sampled for $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ using methods described previously (Swart *et al.*, 1999). A powdered calcium carbonate was collected in transects from coral slabs using a computer-controlled drilling apparatus. All carbonate samples were processed on a Finnigan MAT 251 Mass spectrometer connected to an automated extraction device at the University of Miami. Data are presented in standard delta notation relative to PDB.

RESULTS

ISOTOPIC COMPOSITION OF WATERS

The $\delta^{18}\text{O}$ of precipitation reported in this study in the South Florida area is highly variable. Despite this variability, the data fall near the MWL and have volume weighted mean values for $\delta^{18}\text{O}$ and δD of -2.9‰ and -9.9‰ , respectively (Table 1). The $\delta^{18}\text{O}$ data agree well with precipitation data collected between 1983 and 1988 (Swart *et al.*, 1989) that have mean $\delta^{18}\text{O}$ and δD values of -2.7‰ and -11.4‰ , respectively. Actual $\delta^{18}\text{O}$ values of the precipitation ranged from values as negative as -6‰ during the wet season to values close to 0‰ during the drier portions of the year.

Water from the Everglades is significantly enriched in ^{18}O and D with respect to precipitation (Table 1). Mean $\delta^{18}\text{O}$ for the Everglades samples is $+0.55\text{‰}$, compared to -2.9‰ for precipitation. The highest values occur during the end of the dry season (March–May) with isotopically more negative values in the late wet season (Text-fig. 2). The $\delta^{18}\text{O}$ and δD data fall on a line with a slope of 5.8 ($R^2 = 0.75$), less than the slope of 8 for the MWL (Text-fig. 3). Although $\delta^{13}\text{C}$

Table 1.—Statistical summary of stable isotope and salinity data for surface waters by area and precipitation in South Florida.

Area	Number of samples	Mean $\delta^{18}\text{O}$	S.D. (a) $\delta^{18}\text{O}$	Mean δD	S.D. δD	Mean $\delta^{13}\text{C}$	S.D. $\delta^{13}\text{C}$	Mean Salinity	S.D. (a) Salinity
Everglades	221	0.55	1.59	6.75	10.83	-6.9*	1.9*	(c)	(c)
Florida Bay (total)	1318	1.62	1.00	11.35	6.66	-2.87	2.32	27.9	9.6
Inner	427	1.76	1.06	11.83	7.30	-3.39	2.16	21.6	9.2
Eastern Middle	240	1.80	0.96	11.64	7.39	-2.95	2.45	31.5	6.8
Western Middle	194	1.55	0.67	10.99	5.63	-2.77	2.35	33.9	3.6
Outer	151	1.41	0.60	9.50	4.99	-2.29	2.39	33.8	2.9
Whitewater Bay	247	1.58	1.19	10.07	8.07	-7.33	1.85	13.5	10.1
Ten Thousand Islands	259	1.06	1.31	7.12	7.89	-5.76	2.34	21.6	11.6
Precipitation (b)	23	-2.9	1.48	-9.95	11	(c)	(c)	(c)	(c)

(a) Standard deviation.

(b) Isotopic means for precipitation are weighted by the amount of precipitation.

(c) Not measured.

* Meyers (1990).

of Everglades waters were not measured in this study, they were reported in Meyers (1990) and included in Table 1 for comparative purposes. In general, the isotopic composition of DIC in Everglades waters were negative with a mean $\delta^{13}\text{C}$ of -6.9‰ (Meyers 1990).

The $\delta^{18}\text{O}$ of the water in all of the Florida Bay samples ranges from -2.9 to $+5.7\text{‰}$ with a mean of $+1.62$ (Table 1). The $\delta^{13}\text{C}$ for all of the Florida Bay samples (-2.87‰) is higher than that reported for the Everglades (-6‰ ; Table 1). A time series of the mean $\delta^{13}\text{C}$ values for all stations in South Florida indicate a minimum in 1996 (Text-fig. 4).

The mean $\delta^{18}\text{O}$ for the Whitewater Bay and Ten Thousand Islands areas are positive and $+1.58\text{‰}$ and $+1.06\text{‰}$, respectively (Table 1). In contrast, the mean $\delta^{13}\text{C}$ for both Whitewater Bay and the Ten Thousand Islands area is significantly negative with values of -7.33‰ and -5.76‰ , respectively (Table 1). These values are similar to those reported for the Everglades (Table 1) by Meyers (1990).

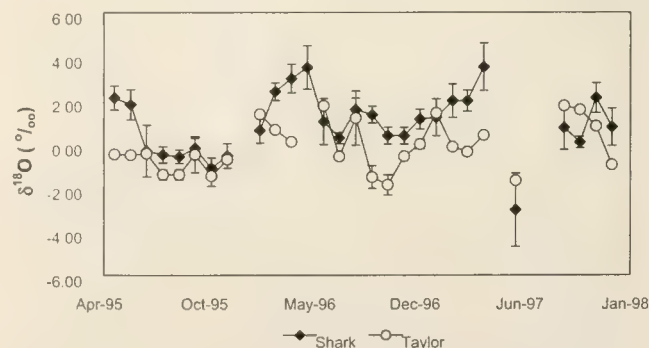
COMPARISON OF OXYGEN AND CARBON ISOTOPIC COMPOSITION WITH SALINITY

In order to examine the variation in the relationships between $\delta^{18}\text{O}$, $\delta^{13}\text{C}$, and salinity further, we have separated Florida Bay into four regions: Inner Florida Bay, Eastern-middle, Western-middle, and Outer Florida Bay (Text-fig. 1). Salinity within these regions increases from east to west across Florida Bay (Table 1), typical of an estuary. The Inner Florida Bay region has the lowest mean salinity of 21.6, while the Western-Middle and Outer Florida Bay regions have a similar mean salinities of 31–33. In general, the mean $\delta^{18}\text{O}$ decreases from east to west across Florida Bay from $+1.8$ to $+1.4\text{‰}$ (Table 1).

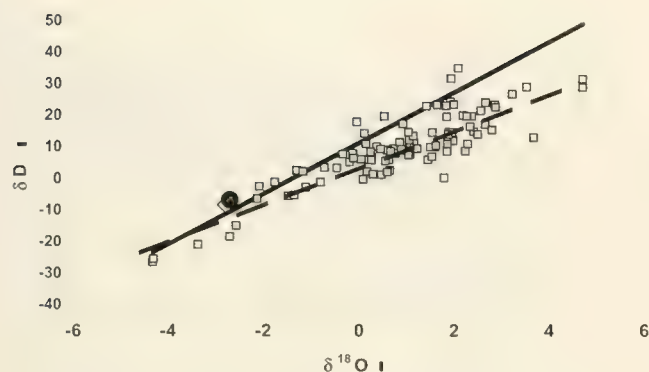
The relationships between $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ with salinity of South Florida estuarine waters are investigated by using $\delta^{18}\text{O}$ vs salinity and $\delta^{13}\text{C}$ vs salinity plots and

then fitting a linear regression through the data (Table 2). When the $\delta^{18}\text{O}$ for each site in Florida Bay is averaged on a monthly basis and compared to the corresponding mean monthly salinity for each station, there is a positive linear correlation ($R^2 = +0.36$; $p < 0.01$) (Text-fig. 5). There is a positive linear relationship between $\delta^{18}\text{O}$ and salinity for each of the four regions of Florida Bay (Table 2; Text-fig. 6). Although the linear regression can explain only 30 percent or less of the variation between $\delta^{18}\text{O}$ and salinity in the Florida Bay regions (Table 2), each of the linear regressions are significant at $p < 0.01$. The linear relationship between $\delta^{18}\text{O}$ and salinity was strongest for the two middle regions of Florida Bay ($R^2 = 0.3$), and weakest for the Outer region of Florida Bay ($R^2 = 0.09$).

There is a variation in the intercepts of the linear regressions for each of the regions in Florida Bay. The linear regressions for the Inner and Eastern-middle areas of Florida Bay predict a $\delta^{18}\text{O}$ at zero salinity of $+0.33\text{‰}$ and -0.83‰ , respectively. The predicted intercept of the linear relationship at zero salinity for the Western-middle and Outer areas of Florida Bay are



Text-figure 2.—Time series of mean $\delta^{18}\text{O}$ for Everglades. Error bars represent ± 1 standard deviation.



Text-figure 3.—Oxygen and hydrogen isotopic composition of Everglades water. Black circle represents volume weighted average isotopic composition of rainfall collected in this study. Open triangle represents isotopic composition of rainfall reported by Swart *et al.*, 1989.

significantly more negative than zero at -2.39‰ and -1.07‰ , respectively.

A positive linear relationship exists between $\delta^{18}\text{O}$ and salinity for the Whitewater Bay and Ten Thousand Islands areas (Table 2). The linear correlation coefficient (R^2) for the Whitewater Bay and Ten Thousand Islands is 0.34 and 0.28, respectively ($p < 0.01$). The predicted intercept of the linear relationship at zero salinity is close to zero for both the Whitewater Bay ($+0.35\text{‰}$) and Ten Thousand Islands areas (-0.2‰ , Table 2).

There is no strong linear correlation between $\delta^{13}\text{C}$ and salinity throughout all of Florida Bay (Text-fig. 7). Similarly there is no strong linear correlation between $\delta^{13}\text{C}$ and salinity within the four regions of Florida Bay (Table 2; Text-fig. 8), except for the Inner Florida Bay area. The Inner Florida Bay area, Whitewater Bay area and the Ten Thousand Islands areas have similar correlations ($R^2 = 0.2$; $p < 0.01$) between $\delta^{13}\text{C}$ and salinity.

CORALS

The $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ data for the skeleton of the coral collected from Lignumvitae Basin have been reported previously (Swart *et al.*, 1996; 1999). The average an-



Text-figure 4.—Five month running mean of the $\delta^{13}\text{C}$ composition of the DIC in all regions studied. Error bars represent $\pm$ one standard error.

nual values for both corals are shown in Text-figure 9. The Manatee Bay coral ($-2.58 \pm 0.3\text{‰}$) is slightly isotopically enriched in $\delta^{18}\text{O}$ relative to the Lignumvitae coral ($-2.04 \pm 0.5\text{‰}$), and has more negative $\delta^{13}\text{C}$ values ($-6.45 \pm 0.43\text{‰}$ vs. $-3.25 \pm 0.58\text{‰}$ for the Manatee Bay coral).

CONTINUOUS SALINITY MONITORING DATA

Continuous salinity data collected from Lignumvitae Basin in Florida Bay are shown in Text-figure 10. The continuous data from Lignumvitae Basin have been averaged into monthly values and are plotted with the FIU/SERP data. The FIU/SERP data represent water samples collected on a single day within the month. Generally the agreement between the two datasets is excellent considering the different temporal resolution between them.

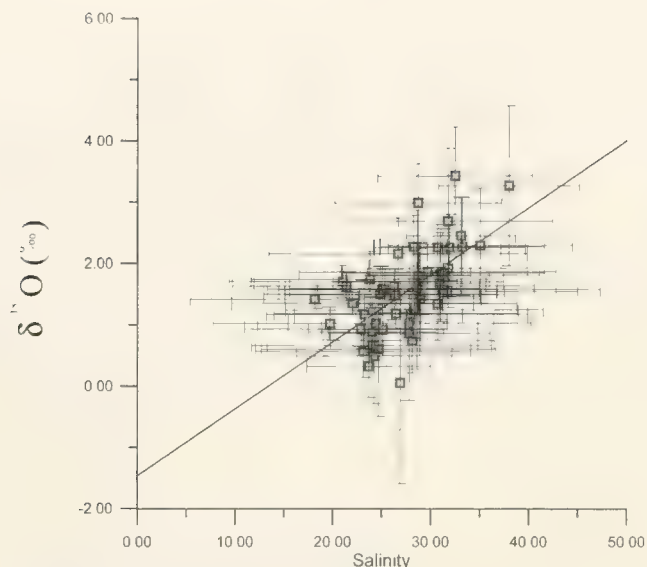
DISCUSSION

SOURCES OF SALINITY VARIATION

Relatively few studies have examined the $\delta^{18}\text{O}$ and δD of precipitation in South Florida. The data pre-

Table 2.—Results of linear regression analyses.

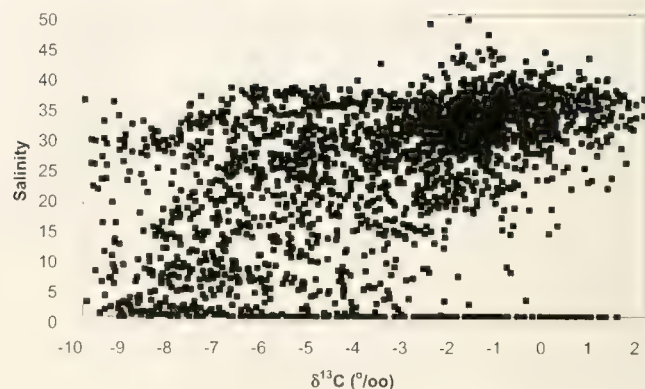
Area	$\delta^{18}\text{O}$ vs. salinity					$\delta^{13}\text{C}$ vs. salinity				
	Intercept	Slope	R^2	Number	P	Intercept	Slope	R^2	Number	P
Florida Bay										
Inner	+0.33	0.06	0.26	537	<0.01	-5.75	0.11	0.20	516	<0.01
Eastern Middle	-0.83	0.08	0.31	293	<0.01	-6.54	0.12	0.11	296	<0.01
Western Middle	-2.39	0.11	0.30	242	<0.01	-7.99	0.16	0.05	244	<0.01
Outer	-1.07	0.09	0.09	194	<0.01	-10.90	0.26	0.10	184	<0.01
Whitewater Bay	+0.35	0.07	0.34	395	<0.01	-8.33	0.10	0.20	364	<0.01
Ten Thousand Islands	-0.2	0.06	0.28	395	<0.01	-7.67	0.09	0.20	336	<0.01



Text-figure 5.—Mean monthly $\delta^{18}\text{O}$ values versus salinity for all sites in Florida Bay. Error bars represent ± 1 one standard deviation.

sented in this study show that the isotopic composition of South Florida precipitation falls near the MWL (Text-fig. 3). It is relatively depleted with volume weighted means of δD and $\delta^{18}\text{O}$ -9.95‰ and -2.90‰ , respectively (Table 1).

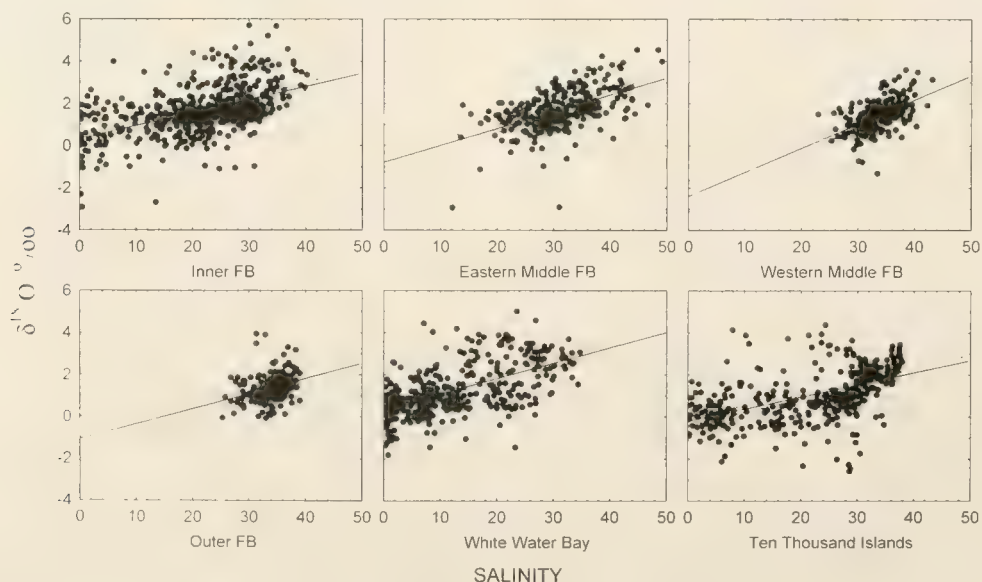
Based on a correlation between δD and $\delta^{18}\text{O}$, the data from the Everglades plot below the MWL (Text-fig. 3). Deviation away from the MWL is a well-known phenomenon and arises through the differential influence of evaporation of the oxygen and hydrogen isotopes. In the case of the Everglades data, the closeness of the slope of the best fit line through the data



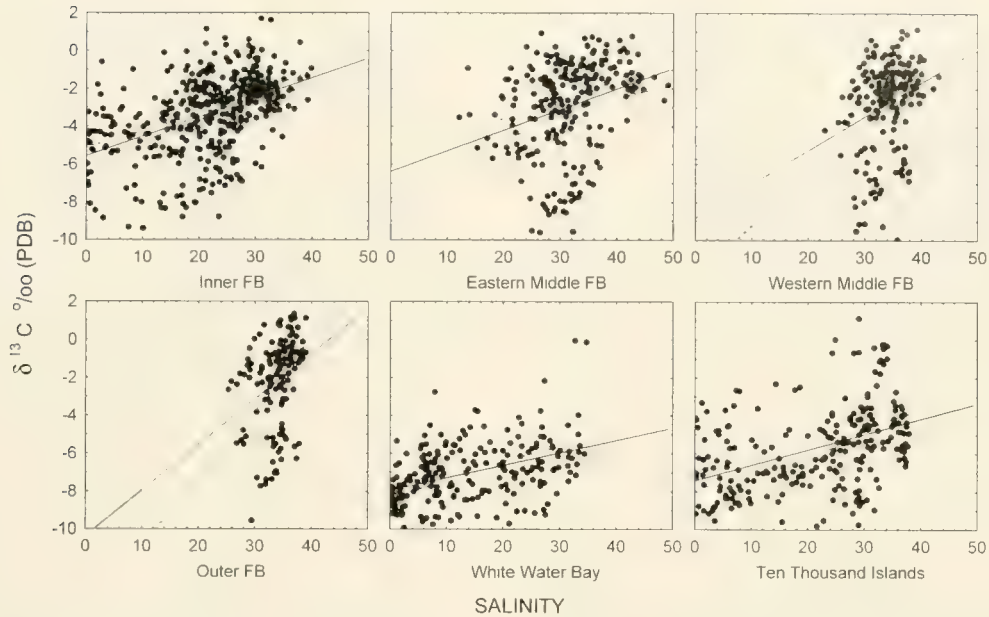
Text-figure 7.—Mean monthly $\delta^{13}\text{C}$ versus salinity for all sites in Florida Bay.

(5.8) to the slope of the MWL, suggests evaporation at a high relative humidity (Gonfiantini, 1986). Meyers *et al.* (1993) predicted a mean relative humidity of 80% for the Everglades based upon a stable isotope evaporation model. The time series trend of the Everglades data (Text-fig. 2) shows some seasonality with isotopically more positive values toward the end of the dry season when evaporation typically exceeds precipitation.

The intercept of the best fit line through the Everglades data with the MWL is similar to the isotopic composition determined for South Florida precipitation (Text-fig. 3). These results indicate that precipitation is the ultimate source of the evaporated water in the Everglades, Everglades water can be distinguished isotopically from its parent precipitation. The mean $\delta^{18}\text{O}$ and δD of the Everglades water is $+0.55\text{‰}$ and



Text-figure 6.—Comparison of the linear relationship between $\delta^{18}\text{O}$ and salinity for the six major areas designated in Text-figure 1.

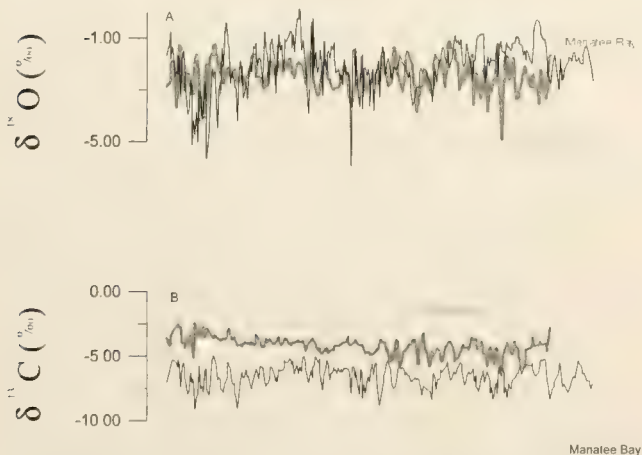


Text-figure 8.—Comparison of the linear relationship between carbon isotopic composition (DIC) and salinity for the six major areas designated in Text-figure 1.

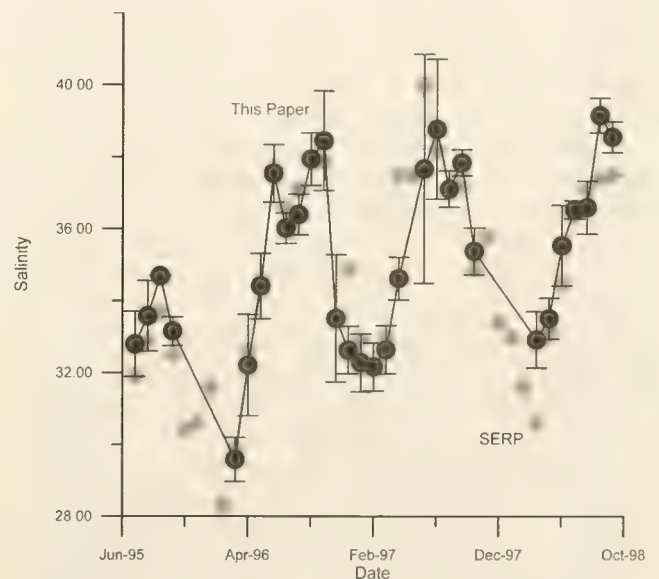
+6.75‰, respectively, as compared to −2.90‰ and −9.95‰ for the precipitation.

Florida Bay exhibits a wide range of $\delta^{18}\text{O}$ values related to evaporation, precipitation, and mixing with water derived from the Everglades, the Gulf of Mexico, and the Florida Reef Tract. The wide range of $\delta^{18}\text{O}$ values was noted by Lloyd (1964) who was unable to exhibit any relationship between salinity and $\delta^{18}\text{O}$. In contrast to the study of Lloyd (1964), the data in this study were collected within a temporal and spatial framework and consequently the apparent poor correlation between salinity and $\delta^{18}\text{O}$ noted by Lloyd can be explained by mixing between different end-mem-

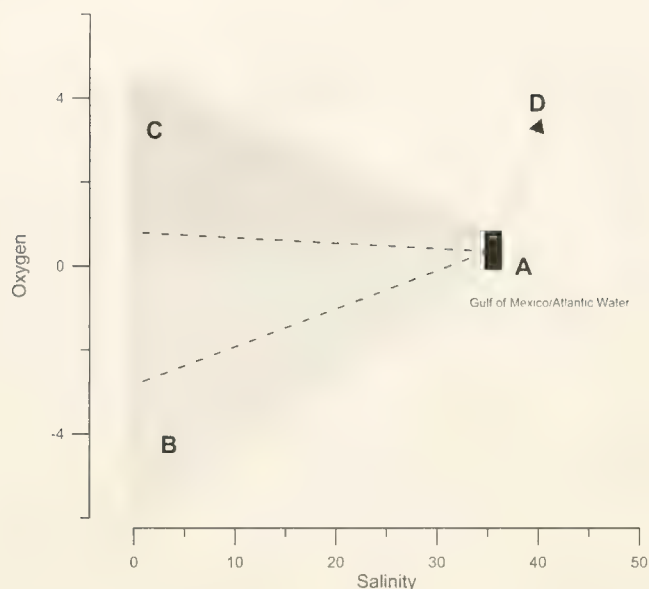
bers with similar salinity, but differing $\delta^{18}\text{O}$ values. These relationships can be visualized on a $\delta^{18}\text{O}$ vs. salinity plot (Text-fig. 11) comparing the $\delta^{18}\text{O}$ composition and salinity of the relevant end-member waters: Everglades, precipitation, and seawater. Data for the seawater end-member are derived from previous studies (Ortner *et al.*, 1995; Leder *et al.*, 1996; Swart,



Text-figure 9.—Oxygen and carbon isotopic data from corals collected from Lignumvitae Bay and Manatee Bay.



Text-figure 10.—Comparison of data collected from the continuous salinity monitoring stations and data collected by FIU on a monthly basis. Salinity data have been averaged from hourly data into monthly values. Error bars represent $\pm$ one standard deviation.



Text-figure 11.—Model for the evolution of waters in the coastal region of Florida Bay showing the salinities and $\delta^{18}\text{O}$ of three end members. Marine water from the Gulf of Mexico and the Atlantic (A) has a salinity of approximately 35.5 and a $\delta^{18}\text{O}$ of $+0.5$ to $+1.5\text{‰}$. This mixes with (B) rainwater ($\delta^{18}\text{O} = 0$ to -6‰ ; mean = -2.9‰) or water from the (C) Everglades ($\delta^{18}\text{O} = -4.5$ to $+4.5\text{‰}$; mean = $+0.55\text{‰}$). Evaporation can take place at any time from any mixture. Evaporation of the marine water will produce a trend along a line (D).

unpublished data), and have a $\delta^{18}\text{O}$ of between $+0.5$ and $+1.5\text{‰}$ and a salinity between 35 and 36. The model proposed herein suggests that South Florida estuarine waters plotting along a linear correlation between $\delta^{18}\text{O}$ and salinity with an intercept of 0 to $+1\text{‰}$ reflect mixing of seawater with Everglades runoff. Estuarine waters plotting along a linear correlation with an intercept near -2‰ or lower indicate mixing of seawater with precipitation. Variation in the intercept between these two extremes reflects varying contributions from both runoff and precipitation and scatter in these relationships reflect the presence of multiple sources and processes such as evaporation (Text-fig. 11).

The intercept of the linear correlation between $\delta^{18}\text{O}$ and salinity changes from being more negative in the western areas (Outer and Western-middle) of Florida Bay to being more positive in the eastern areas (Eastern-middle and Inner) of Florida Bay (Table 2; Text-fig. 11). These results indicate that inputs of precipitation is most responsible for varying salinity in the western areas of Florida Bay. Conversely, runoff from the Everglades is more important for the variation in salinity in the eastern portion of Florida Bay. For Whitewater Bay and the Ten Thousand Islands areas, the intercept of the correlation between $\delta^{18}\text{O}$ and sa-

linity is close to zero (Table 2) suggesting that the salinity variation in these regions is principally a result of runoff from the Everglades, and in particular from Shark Slough.

SOURCES OF CARBON ISOTOPIC VARIATION

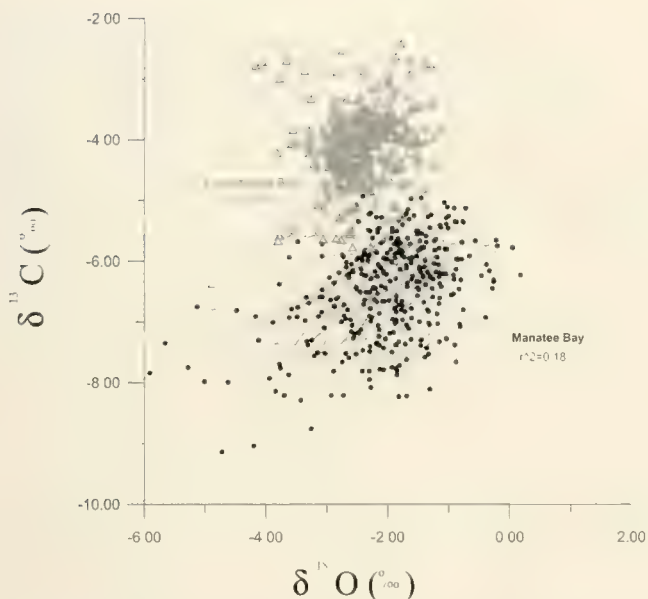
The $\delta^{13}\text{C}$ of the DIC in all the surface waters from the estuarine environments was highly variable and showed a limited relationship with salinity (Table 2 and Text-fig. 7 & 8). Stronger correlations between $\delta^{13}\text{C}$ and salinity were observed in the areas most influenced by runoff from the Everglades. These areas include the Inner area of Florida Bay, White Water Bay and the Ten Thousand Islands. Although the $\delta^{13}\text{C}$ of the Everglades was not measured routinely throughout this study, measurements that were made on selected samples from the Everglades reveal that these waters had negative $\delta^{13}\text{C}$ values (Meyers, 1990). Hence when these waters flowed into the marine environment, the result was a strong correlation between $\delta^{13}\text{C}$ and salinity. In contrast, the absence of a strong relationship between $\delta^{13}\text{C}$ and salinity in the more saline portions of Florida Bay supports the relative lack of influence of Everglades waters on these portions of Florida Bay.

Despite the absence of a correlation between $\delta^{13}\text{C}$ and salinity in the central and western areas of Florida Bay sites, the waters at these sites show a considerable amount of variability in $\delta^{13}\text{C}$ which is probably related to local remineralization of organic material. The most negative $\delta^{13}\text{C}$ values that are attained in Florida Bay (mean = -3‰) is a reflection of the more marine nature of this organic material compared to the White Water Bay and Ten Thousand Island area ($\delta^{13}\text{C}$ between -5‰ and -7‰) where most of the organic material is derived from terrestrial sources.

CORALS

Considering the relatively poor correlation between salinity and $\delta^{13}\text{C}$ of DIC, there appears to be little utility in relating the $\delta^{13}\text{C}$ of calcareous skeletons to input of freshwater except in the environments which are the closest to the Everglades. In the central areas of Florida Bay, where it has been established that there is a relative absence of freshwater input using the $\delta^{18}\text{O}$ data, the changes in the $\delta^{13}\text{C}$ of calcareous organisms can be interpreted as reflecting increased oxidation of organic material, perhaps leading to an increase abundance of nutrients.

The correlation between the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of coral skeletons can be used as an indicator of the relative influence of freshwater. Corals from areas where there is relatively little influence of freshwater will have relatively little correlation between the two isotopes in



Text-figure 12.—Relationships between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ in the coral skeletons from Lignumvitae Basin and from Manatee Bay. Note that in the Lignumvitae data there is no correlation between the two isotopes ($R^2 = 0.04$) as predicted from an absence of a correlation in the two isotopes in the water at that site. In Manatee Bay however there is a correlation between the two isotopes which is statistically significant at the 99% level ($R^2 = 0.14$).

their skeletons, while corals influenced by runoff should have a better correlation. These correlations can be seen in data from the coral collected from Manatee Bay which shows a strong positive correlation between skeletal $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ ($R = .42$, $n = 362$, $p > .0001$). In contrast, corals from Lignumvitae Basin show no correlation between the two isotopes ($R = 0.003$, $n = 1894$, $p = \text{not significant}$) (Text-fig. 12). These correlations are similar to the relationships seen between the $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ of waters. For example, results from a linear regression model between $\delta^{13}\text{C}$ of DIC and salinity has an R^2 of 0.2 (Table 2). In western-middle Florida Bay, where the Lignumvitae Basin is located, an R^2 of 0.05 is obtained (Table 2).

APPLICATION TO EXISTING PALEOENVIRONMENTAL DATA

Combining the salinity relationship between Lignumvitae Basin along with $\delta^{18}\text{O}$ record of the coral skeleton collected from Lignumvitae Basin, attempts have been made at estimating salinity variations in other regions of Florida Bay (Swart *et al.*, 1996; 1999). Based on data presented in this paper, however, the equation linking the skeletal $\delta^{18}\text{O}$ and salinity in Lignumvitae Basin (Swart *et al.*, 1999) is not valid for other areas of Florida Bay. Consequently different equations for estimating salinity from $\delta^{18}\text{O}$ need to be derived for every location. While this is impractical in

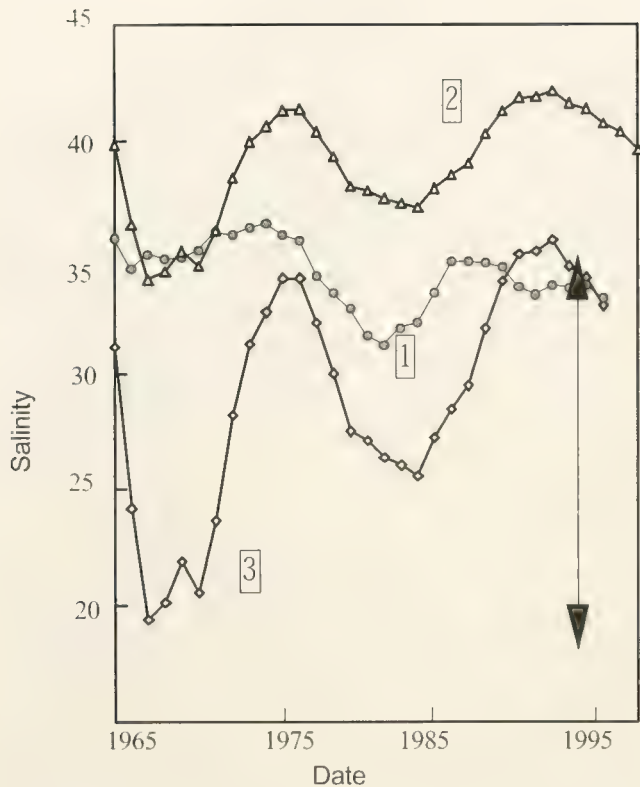
real terms, one can obtain an idea of the influence of the variations by calculating the relationships between salinity and $\delta^{18}\text{O}$ for the different geographic sub-regions designated for Florida Bay (Text-figs. 1, 6). As an example of the influence that these different relationships have on the calculation of the salinity from a $\delta^{18}\text{O}$ record, we examined the $\delta^{18}\text{O}$ record of a coral from Lignumvitae Basin and a coral of a similar genus growing in Barnes Sound near the mouth of Manatee Bay. In order to compare the salinity estimates, we used three methods to determine the salinity at the mouth of Manatee Bay. These are (1) the transfer function approach presented by Swart *et al.* (1999) using the $\delta^{18}\text{O}$ of coral skeletons growing in Lignumvitae Basin and the modern salinity correlations between the two basins, (2) using a coral actually growing in a site and the correlation between salinity and $\delta^{18}\text{O}$ for Lignumvitae Basin, and (3) using the Manatee Bay coral and the salinity vs. $\delta^{18}\text{O}$ relationship presented in this paper. We then compared these salinity estimates directly with measurements by FIU/SERP and the University of Miami in Barnes Sound. In the first comparison, the data from the coral growing in Lignumvitae Basin was converted to salinity using the equation presented by Swart *et al.* (1999) which related salinity to the temperature (T) and the $\delta^{18}\text{O}$ of the coral skeleton (equation 1). This provided an estimate of salinity with a slightly greater amplitude than the Lignumvitae coral, but significantly higher than the range in salinity measured in Manatee Bay (Text-fig. 13).

$$\text{Salinity} = 4.988\delta^{18}\text{O}_{\text{coral}} + 1.18T + 19.62 \quad (1)$$

In the second approach equation 1 was also used, but in this case the data from the coral actually growing near the mouth of Manatee Bay was used (Text-fig. 13). This gave an estimate similar in pattern to the method used previously, but with much higher salinity estimates than the salinities actually measured (Text-fig. 13). The third method uses the new relationship between salinity and $\delta^{18}\text{O}_{\text{water}}$ shown in Table 4. In order to convert the $\delta^{18}\text{O}$ of the coral skeleton to salinity we used the relationship established by Leder *et al.* (1996) between temperature and skeletal $\delta^{18}\text{O}$ for the species *Monastrea annularis* and assumed an annual mean temperature of 25°C . Combining these two equations a new formula can be derived which is specific for corals growing in the inner portion of Florida Bay. This relationship is shown in equation 2.

$$\text{Salinity} = 4.148\delta^{18}\text{O}_{\text{coral}} + 0.978T + 9.33 \quad (2)$$

The results of these three calculations together with the range of salinities actually measured at the site in Manatee Bay are shown in Text-figure 13. This visual comparison shows that the best estimate of salinities



Text-figure 13.—Line (1) represents the salinity in Barnes Sound estimated using the $\delta^{18}\text{O}$ data from the coral in Lignumvitae Basin (Swart *et al.*, 1996, 1999). Line (2) represents the salinity estimate calculated from the $\delta^{18}\text{O}$ of the Manatee Bay coral using the relationship between salinity and $\delta^{18}\text{O}_{\text{water}}$ established for Lignumvitae Basin. Line (3) is the new relationship between salinity and $\delta^{18}\text{O}$ for the inner region of Florida Bay established in this paper (Table 4). The ranges in salinity measured by FIU and presented in this paper are indicated by the arrow.

measured at the site are provided by the method in which we used the correlation between salinity and $\delta^{18}\text{O}_{\text{water}}$ for inner Florida Bay. Previously estimates for the salinity in this portion of Florida Bay are therefore likely to have been too high (Swart *et al.*, 1999). However, in spite of the distance between the two locations (Lignumvitae Basin and Manatee Bay), the coral in Lignumvitae Basin shows a similar temporal pattern in $\delta^{18}\text{O}$ to the Manatee Bay Coral and with the appropriate calibration the Lignumvitae coral record (Swart *et al.*, 1996) can be used to estimate salinities in other portions of Florida Bay.

CONCLUSIONS

1) Relationships between salinity and $\delta^{18}\text{O}$ vary according to relative distance from the Everglades. This changing relationship is caused by an increasing influence of rainfall compared to runoff in controlling salinity variations. For example, the western portion of Florida Bay appears not to be significantly influenced by runoff from the Everglades and salinity variations there are related to changes in the amount of precipitation. Application of a constant salinity vs. $\delta^{18}\text{O}$ relationship in the interpretation of $\delta^{18}\text{O}$ values of calcareous organisms from South Florida estuaries is not appropriate.

2) Carbon isotopic variations in Florida Bay are related to the oxidation of organic material. Large variations in the $\delta^{13}\text{C}$ of the DIC occur both within saline and freshwater environments. Within the saline environments, there is little relationship between salinity and $\delta^{13}\text{C}$ while in the freshwater environment, there is a strong correlation between salinity and $\delta^{13}\text{C}$.

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CHAPTER 3

SEDIMENT DYNAMICS OF FLORIDA BAY MUD BANKS ON A DECADAL TIME SCALE

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ABSTRACT

Ecosystem management requires knowledge of environmental dynamics. If historical environmental records do not exist, other methods must be employed to obtain this information. A well-known geochemical procedure that supplies this type of data is the use of natural radioactive nuclides to “date” the timing of events. Of the many naturally occurring nuclides, ²¹⁰Pb is the best suited for gauging the timing of episodes in Florida Bay. The age-depth relationships were calculated using the ²¹⁰Pb method for thirty-five sites within Florida Bay. The ages were independently confirmed by comparing the distribution of known concentrations of atmospherically anthropogenic lead recorded in dated cores to similar data in an annually banded coral. Sediments in the western and northern fringe of Florida Bay are accumulating at ≈ 0.3 cm/yr, a rate similar to that of sea level rise. In the north-central part of the bay, sediments are accumulating at a faster rate of ~ 1.0 cm/yr. The highest rate, ≥ 2.0 cm/yr was measured in the northeastern part of the bay on the bank between Pass and Lake Keys. The rapid rate of accumulation in the northeastern part of the bay permits the deciphering of biological and geochemical changes with an accuracy of about two years. In contrast, the intermediate sediment rate in the central part of the bay provides adequate age-depth for relationships deciphering the environmental record of the past 100 years.

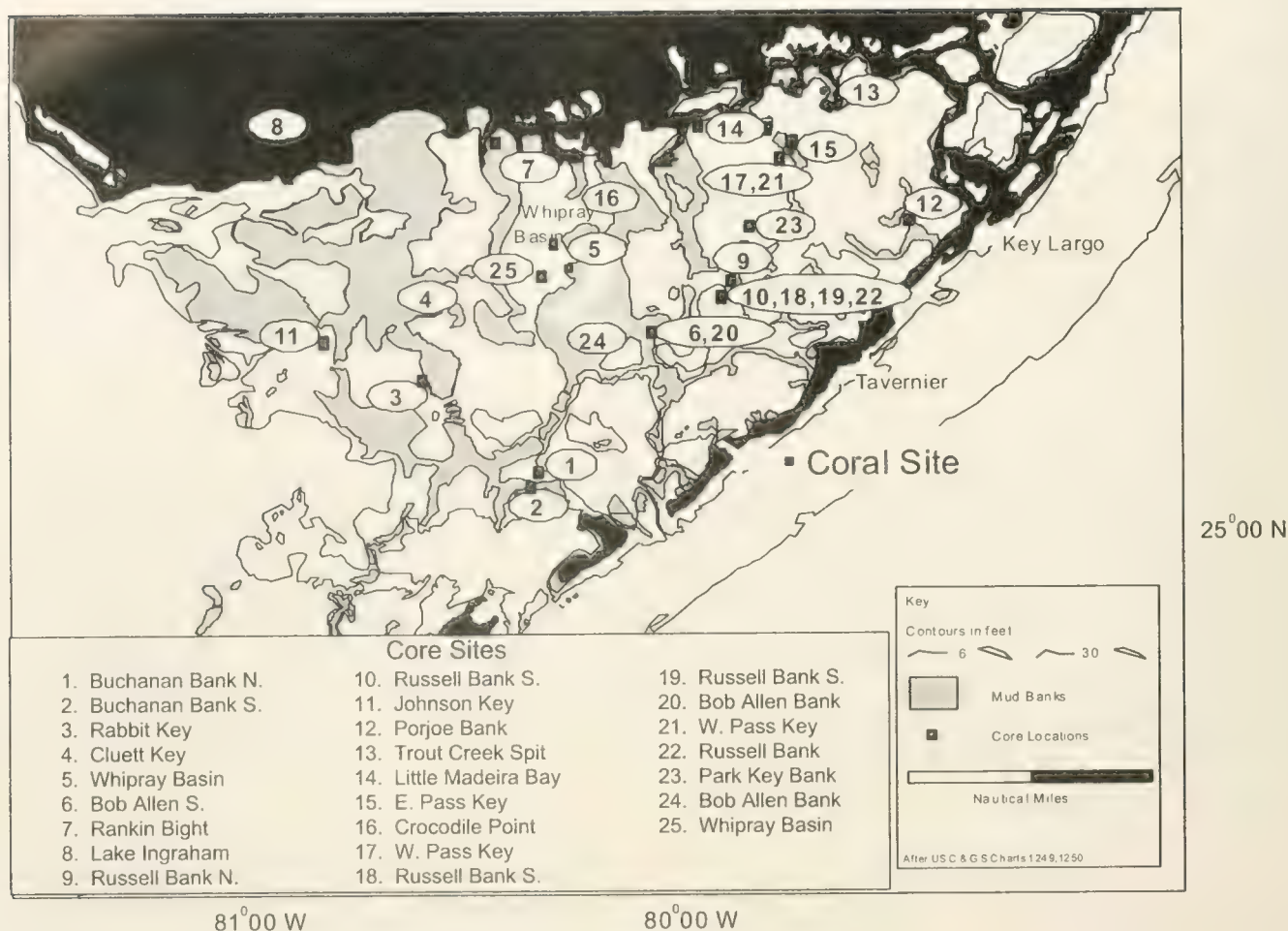
INTRODUCTION

Any retrospective analysis of natural systems requires a temporal frame of reference against which dynamic processes can be measured. The lack of adequate historical environmental records within the Florida Bay system necessitated the development of a method to determine the timing of environmental alterations. Conventional wisdom implies that the natural hydrology was significantly altered over the past 100 years. However, prior to any “restoration” effort, it is prudent to determine what changes are the result of natural processes and which are not. The keys to this information lie within the sedimentary record. To read this record properly, the first requirement is to establish accurately a temporal frame of reference. A program was initiated in 1994 to define the environmental record with the sediments of Florida Bay. The project was a cooperative between the South Florida Water Management District, the U.S. Geological Survey, and the Great Lakes Environmental Research Laboratory (N.O.A.A.).

Sediments have been accumulating in Florida Bay for approximately 4000 years (Scholl, 1964). The basal sediments are brackish and freshwater peats and marls, similar to those presently accumulating in the Everglades (Davies and Cohen, 1989). Overlying these

sediments are marine sediments that form a network of mud banks and islands that partition the bay into more than 30 small basins. The basins range from one to four meters in depth and are up to a few kilometers wide (Text-fig. 1). The bulk of the sediments is in the banks and islands and is predominantly silt- and clay-sized carbonate particles. Most of the mud is derived from the physical breakdown of larger skeletal fragments, with a contribution from calcareous algae that produce micron-sized carbonate needles (Boscence, 1989a). The minor amount of sand-sized and coarser material is the result of the debris from a great variety of calcareous invertebrates living in the bay (Boscence, 1989a).

Although much work has been devoted to the origin, composition, and distribution of sediments in Florida Bay (Boscence, 1989b), the processes that have created the mudbanks and their rate of formation are poorly understood. It is commonly held that the south or west sides of the mud banks are accreting while the northern and eastern sides are eroding (Wanless and Taggart, 1989). ¹⁴C dating of peats and carbonate sediments provide a general picture of the time of sediment formation. However, these data do not address the dynamics of sediment transport—particularly in regard to the mobile, fine-grained particles. This information is important in defining stratigraphic relation-



Text-figure 1.—Location of coring sites in Florida Bay.

ships within the deposits. To obtain this information, chronological methods using short-lived isotopes were employed.

The requirements for an isotope to be a candidate for dating sediments are that: (1) the chemistry of the isotope (element) is known; (2) the half-life is known; (3) the initial concentrations of the isotopes are known or can be accurately estimated; (4) the only change in concentration is due to radioactive decay; and (5) in order to be useful, it must be relatively easy to measure. If all these conditions are met, the effective range for each isotope is about eight half-lives. Four naturally occurring isotopes (^7Be , ^{14}C , ^{137}Cs , and ^{210}Pb) satisfy these criteria and have been found useful for measuring sedimentary dynamics in Florida Bay over the past 100 years.

^{210}Pb is a common radioisotope that has become a mainstay of radiometric dating of sediment deposited during the last century (Goldberg, 1963). This method is based on a radioactive disequilibrium between ^{210}Pb ($t_{1/2} = 22.3$ yr) and its parent, ^{226}Ra ($t_{1/2} = 1600$ yr).

The radioactive disequilibrium is the result of the separation in the decay chain caused by the diffusion of the intermediate daughter, ^{222}Rn . The physical and chemical process that lead to this disequilibrium have been described and critiqued in reviews by Robbins (1978) and Appleby and Oldfield (1992).

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ing to collect and section cores; to those people we are extremely grateful.

PROCEDURES

SAMPLING PROCEDURES

Twenty-five locations were selected for coring in Florida Bay to obtain a comprehensive overview of the different environments (Text-fig. 1). In keeping with the goal of the program—to develop a method of establishing a sediment chronology—most coring sites were located on the accretionary side of the mudbanks. It is there that the potentially longest sediment record is likely. Additional cores were collected in other environments, such as on the “erosional” side of a mudbank (Site 18—Russell Bank and Site 12—Porjoe Bank), within the central part of selected basins (Site 5—Whipray Basin; Site 7—Rankin Bight; Site 8—Lake Ingraham) and on the fringe of the Everglades (Site 13—Trout Creek Spit, Site 14—Little Madeira Bay and Site 16—Crocodile Point). Duplicate cores were taken at selected sites. In all, 27 cores were analyzed. The cores (10 cm i.d.) were collected with a conventional piston coring device.

All cores were driven to the limestone surface and averaged ~1.5 meters in length. Extreme care was exercised to preserve the sediment-water interface and to minimize disturbance. Prior to sampling, each core was x-rayed to determine the presence of laminations and to evaluate the extent of mixing. If there was no observable disturbance during sampling, handling, or transport to the laboratory, the cores were sectioned into 2 cm intervals for analysis. Cores located on Buchanan Bank (North and South), on Cluett Key, Russell Bank north, and on the eastern part of Pass Key were disturbed and therefore were not analyzed.

LABORATORY ANALYSIS

Wet and dry bulk density, acid insoluble residues, loss on ignition, and grain size analysis were determined for each interval (Holmes *et al.*, 1998). Since ^{210}Pb is adsorbed on the clay-sized particles, analyses were performed on the <0.062 mm fraction. The total ^{210}Pb content of the sediment samples was measured on freeze-dried subsamples by both alpha spectrometry, with selected samples also analyzed by gamma techniques. The samples, which were >99% carbonate, were “ashed” at 450°C for 6 hrs to destroy any organic material, and dissolved in 8N HCl. The alpha spectrometry procedure closely followed the method detailed by Flynn (1968). Overall counting uncertainties were $\pm 2\%$. Replicate samples were analyzed by gamma methods at the Woods Hole USGS Laboratory (M. Bothner and M. Ten Brink) as well as at the Great Lakes Environmental Research Laboratory (J. Rob-

bins) and the results were within counting error of measurements made by alpha methods. The ^{226}Ra values were measured on selected samples by gamma spectrometry. Further detail of the analytical procedures and results from the replicate analyses are presented in Holmes *et al.* (1998).

RESULTS AND DISCUSSION

SITE CHARACTERIZATION

In this study, attention was given to the selection of coring sites that were thought to contain well-preserved sediments and high accumulation rates. Coring focused on the recovery of finely laminated sediments, which generally indicate a lack of physical or biological mixing (Ball *et al.*, 1967; Shinn, 1968; Wanless and Taggart, 1989). Three factors are thought to contribute to the formation of the laminated sediments in Florida Bay:

1. Rapidly deposited mud becomes quickly de-watered by as much as 50% so that they become sufficiently cohesive to exhibit pseudo-conchoidal fracture and can resist erosion.

2. The interior of the Bay is characterized by extreme variations in temperature and salinity relative to the open Gulf of Mexico or the Atlantic Ocean. These fluctuations limit the diversity of burrowing organisms that can live in the Bay.

3. Florida Bay sediments are rich in sulfide (500–5000 μM), which inhibits biological activity (William Orem, 1998, personal communication).

The combination of these factors creates an environment wherein short-lived radionuclides can be used successfully to measure sedimentation rates.

Geochemical Models

The calculation of “ages” by the ^{210}Pb method is usually based on one of two models: the constant rate of supply model or the constant initial concentration model. The constant rate of supply (CRS) model assumes that the flux of ^{210}Pb is constant over time regardless of how the sediment flux might vary. The constant initial concentration model is based on the assumption that the concentration of ^{210}Pb at time zero (when the sediment was deposited) has been constant over time. Robbins *et al.* (2000) examined several variations of these models. As a result, a secular equilibrium model, which assumes that a fraction of the ^{210}Pb present in the sample must be in equilibrium with ^{226}Ra , and that there is a constant flux of ^{210}Pb with the attendant adsorption, seems to be the most appropriate model for these sediments.

Individual cores were analyzed by applying a best-fit curve to the data using an unweighted Marquardt-Levenberg parameter optimization method (Press *et*

Table 1.—Concentration of ^{210}Pb in *Penicillus* sp from site in northeastern Florida Bay.

Sample no.	Location	Total Pb-210 activity (dpm/g)	Latitude	Longitude
June 1994				
1	Peterson Keys	2.32	24.7330	80.7500
2	Russell Key	4.02	25.0660	80.6330
3	Rabbit Keys	1.22	24.9900	80.8330
4	Bob Allen Key	1.93	25.0300	80.6730
5	Johnson Basin	1.70	25.1330	80.9250
August 1994				
1	Buttonwood Sound	3.64	25.0853	80.4542
2	Buttonwood Sound	2.79	25.0933	80.4480
3	Buttonwood Sound	3.92	25.1008	80.4425
4	Buttonwood Sound	3.49	25.1072	80.4367
4U	Buttonwood Sound	2.43	25.1072	80.4367
5	Buttonwood Sound	2.23	25.1128	80.4438
5A	Buttonwood Sound	2.56	25.1128	80.4438
6	Buttonwood Sound	2.24	25.1063	80.4492
8	Buttonwood Sound	4.33	25.0908	80.4613
9	Buttonwood Sound	2.81	25.0963	80.4675
10	Buttonwood Sound	3.14	25.1033	80.4620
11	Buttonwood Sound	2.22	25.1113	80.4553
13	Buttonwood Sound	1.77	25.1242	80.4567
17	Buttonwood Sound	3.55	25.1147	80.4755
18	Buttonwood Sound	3.58	25.1228	80.4688
19	Buttonwood Sound	4.16	25.1295	80.4642
19D	Buttonwood Sound	1.90	25.1295	80.4142
25	Little Maderia Basin	8.66	25.1600	80.6233
26	Little Maderia Basin	6.10	25.1342	80.5833
October 1994				
94-glw-201HAL	Lignum Vitae Basin	0.72	24.9370	80.6957
94-glw-201PEN	Lignum Vitae Basin	1.11	24.9370	80.6957
94-glw-202HAL	Twinkeys	0.44	24.9617	80.6669
94-glw-202PEN	Twinkeys	1.35	24.9617	80.6669
94-glw-203PEN	Spy Keys	1.96	24.0123	80.7644
94-glw-204HAL	Twin Key Basin	0.59	24.9898	80.7839
94-glw-204PEN	Twin Key Basin	1.44	24.9898	80.7839
94-glw-205PEN	N. Rabbit Key	1.86	24.9816	80.8242
94-glw-207HAL	Peterson Bank	0.85	24.9189	90.7472
94-glw-207PEN	Peterson Bank	1.97	24.9189	90.7472

HAL = Halameda, U = Udotea, PEN = Penicillis, D = Dasycladaceae, A = Duplicate.

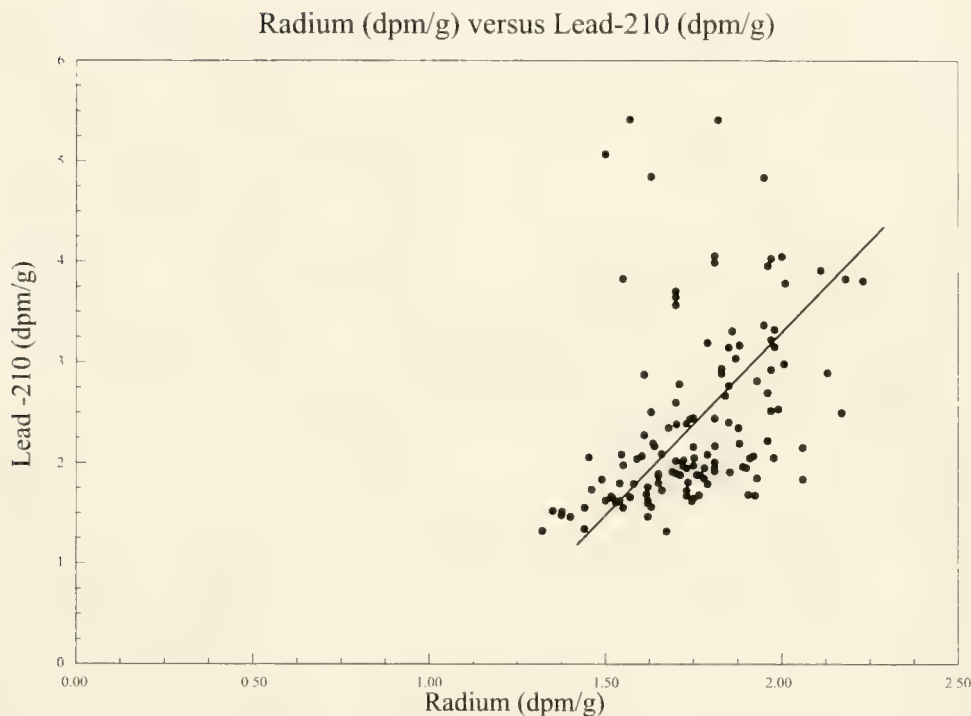
al., 1989). A distinct advantage of this procedure is that all data points, including negative values (which are the result of counting errors, etc.), are used in the sediment accumulation rate calculations. This method has the further advantage of correcting for the 'old age' error, which is inherent in many other best-fit interpolation routines.

Special Geochemical Considerations (Florida Bay)

^{210}Pb dating of marine sediments in the coastal environment is generally complicated by the multiplicity and variability of sources and by physical perturbations of sediment mixing. Thus, the assumptions used in correctly applying ^{210}Pb as a geochronological tool can be seriously violated. However, in northeastern Florida Bay there are a variety of conditions, in ad-

ditional to the physio-chemical conditions previously enumerated that suggest that the ^{210}Pb distribution can provide a sound basis for dating the sediments.

First, a major source of excess ^{210}Pb is the atmospheric flux of ^{210}Pb . In Florida Bay, input from other sources such as groundwater and *in situ* production (via ^{222}Rn) must also be considered. Recent data by Chanton and Burnett (1995) have demonstrated high levels of ^{222}Rn in Florida Bay waters. The likely source is ground water exchange with the elevated levels of parent radionuclides in the underlying Pleistocene rocks. A measure of this reactivity is the measurement of ^{210}Pb activities in the carbonate secreted by the short-lived algae *Penicillus* sp. This alga, which has a life span of ~45 days, is a good monitor (Stockton *et al.*, 1967). The concentration of ^{210}Pb in the algal car-



Text-figure 2.—Plot of the ^{226}Ra activity versus the total ^{210}Pb activity showing a positive relationship with the sediments of Florida Bay ($r^2 = 0.68$).

bonates is highest in areas where there is very little sediment covering the “bedrock” (Table 1). This is consistent with a ground water or bedrock source and would provide a constant flux of ^{210}Pb to the waters of Florida Bay.

Second, even though Rude and Aller (1991) measured the maximum excess ^{210}Pb activity (1.1 dpm/g) to be only about half the background (noise) at the top of the core on Bob Allen Bank, there are a number of characteristics of the ^{210}Pb and ^{226}Ra profiles that appear to be favorable for geochronological purposes:

1. The radium values vary within a limited range (<20%) over the one-meter long cores.

2. Sediment mixing, as evidenced from a 20-cm zone of nearly constant excess ^{210}Pb activities, was confined to the surface of the core. Conventional steady-state sediment mixing and accumulation models can be accurately used to determine a mixing depth and/or mixing rate as well as a sediment accumulation rate (Robbins *et al.*, 2000).

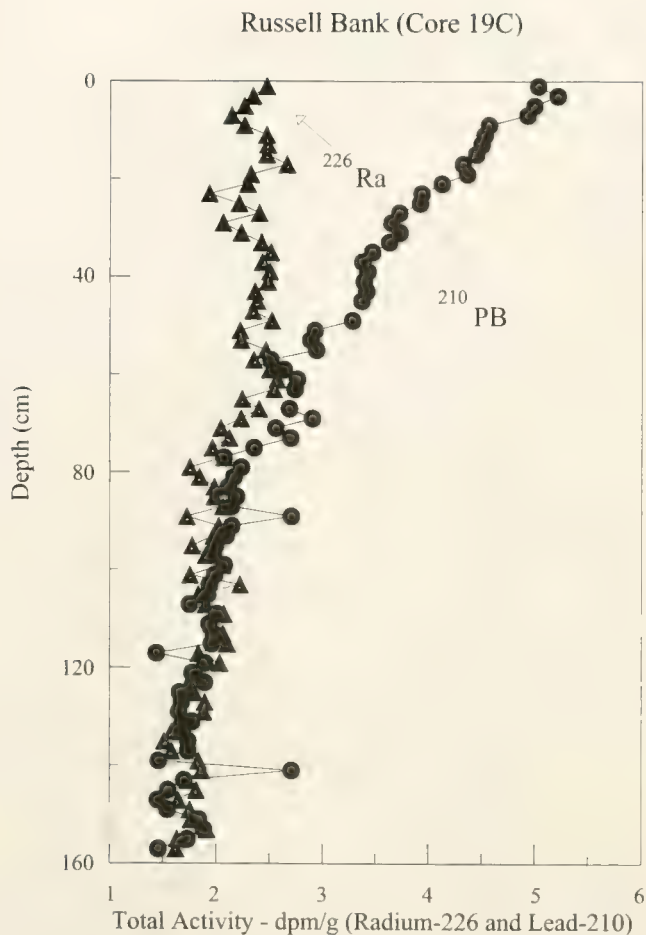
3. Rude and Aller (1991) calculated a mean linear accumulation rate of 1 cm/yr at the Bob Allen Key site which favors the use of reasonably short sediment cores to reconstruct historical records of system changes over the past 100 years.

^{210}Pb and ^{226}Ra Distribution

Calculating “ ^{210}Pb ages” according to the model of Robbins *et al.* (2000) requires the determination of a

portion of the ^{210}Pb that is “supported” by ^{226}Ra . A number of investigators assume that the radium distribution is constant and equal to the value where the total ^{210}Pb activity is constant with depth. They use this value to subtract from the total ^{210}Pb , eliminating the need for independent radium measurements. In order to validate this assumption for the Florida Bay sediments, a large number of radium measurements were made on samples from eight cores. These cores were chosen to represent various environments of the Bay. The Bob Allen Bank cores (6A and 6C), Russell Bank cores (19B and 19C), and Pass Key Bank cores (7D and 17G) were taken from the accreting sides of the banks. The Whipray Basin core (5G), Trout Creek Spit core (13), and Crocodile Point core (16B) represent the non-accreting fringing environments.

In each core from an accreting environment, radium systematically decreased with depth. A linear best-fit of the radium versus depth for individual cores had r -squared values (goodness of fit) which ranged from 0.6–0.9. The slopes and the surface intercept of the individual curves varied within narrow limits, between -0.002 – -0.003 for the slope and 1.9–2.2 for the surface intercept. The coherence of the radium distributions between these cores suggested that a singular expression, $^{226}\text{Ra}_{\text{cal}} = -0.0025(\text{depth}) + 2.0$ (where cal = calculated value) could be used to describe the radium distribution on accreting banks (Text-fig. 2).

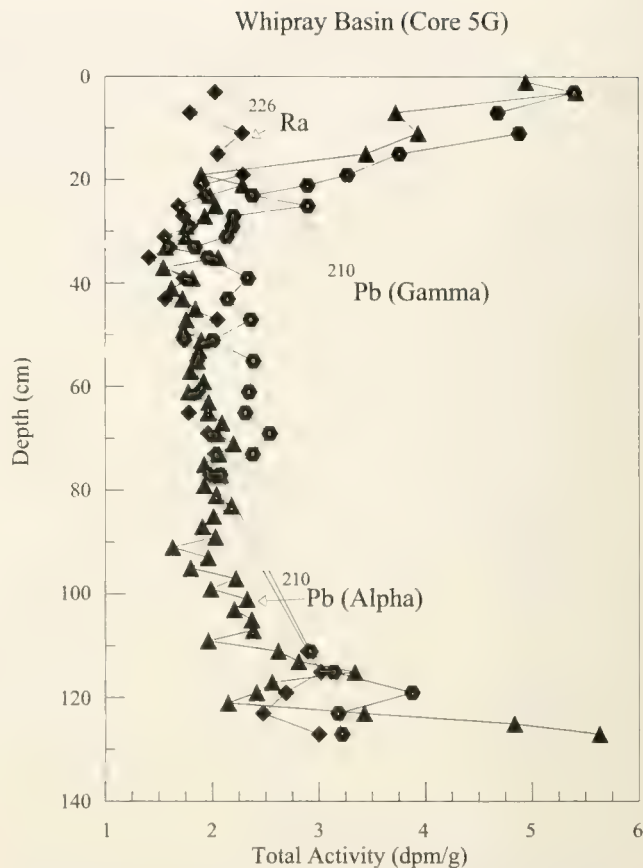


Text-figure 3.—Distribution of ^{226}Ra and total ^{210}Pb in the Russell Bank (Core 19C).

However, for non-accreting banks, where ^{210}Pb activity approaches a minimum in the upper part of the cores, the similar, more generic relationship was determined for ^{210}Pb and radium $^{226}\text{Ra}_{\text{dpm/g}} = 0.16 \text{ Total } ^{210}\text{Pb}_{\text{dpm/g}} + 1.37$ (where dpm/g + total activity). Comparison of ages using calculated versus measured radium values yielded insignificant differences.

The total ^{210}Pb activities for all samples ranged from 1.5–6.0 dpm/g. Subtracting a background value of 2.2 dpm/g for the radium content of the most recently deposited sediments; the maximum excess ^{210}Pb signal was 3.8 dpm/g. A typical plot of excess ^{210}Pb vs. depth from Russell Bank (Core 19C) demonstrates that Florida Bay sediment are in sufficient disequilibrium for calculating accurate geochronology (Text-fig. 3). Text-figure 3 clearly shows that a discernable difference can be observed in ^{210}Pb and ^{226}Ra down to a depth of 100 cm. This diagram also shows the consistent decrease in radium with depth.

The core in Whipray Basin (5G) has high ^{210}Pb activity at the top and, interestingly, also elevated activ-



Text-figure 4.—Distribution of ^{226}Ra and total ^{210}Pb in the Whipray Basin Core 5G. Also plotted is the total ^{210}Pb as determined by gamma spectroscopy that demonstrates very good agreement between the two methods.

ity at the bottom (Text-fig. 4). Gamma spectrometry measurements of these cores suggest that the increased activities observed in the bottom sediments are likely the result of elevated radium and uranium activities. This phenomenon has been detected in the cores taken within the Everglades; in cores from the northern portion of Florida Bay: Rankin Bight (Site 7), Johnson Key (Site 11), Trout Creek (Site 13), and Little Madeira Bay (Site 14); and in cores near the islands in the southern Bahamas (Tedesco and Aller, 1997). The remaining cores show a conventional exponential decrease in excess ^{210}Pb with depth.

The most obvious difference between these cores appears to be the depth at which apparent equilibrium (*i.e.*, total activity equals supported activity) is reached. This is clearly seen by comparison of the S. Russell Bank (19C) and the Whipray Basin (5G) cores. Age calculations for the S. Russell Bank cores indicate that the bottom sediments are at least 150 years old, whereas the Whipray Basin cores reach “equilibrium” in the upper 20 to 40 cm and the bottom sediment has been ^{14}C dated as 3300 years BP. The Pass Key cores

Table 2.—Core location, average rate of accumulation for the last 100 years, and total excess ^{210}Pb inventory of cores used in this chapter.

Site	Core No.	Location		Rate cm/yr	Inventory dpm/cm ²	Comment
		N	W			
Rabbit Key Basin	3B	24 59.06	80 50.25	0.35 ± 0.05	3.3	Northern edge of basin in a grass bed.
Whipray Basin	5G	25 04.26	80 44.31	0.37 ± 0.06	8	Eastern side of the basin in a barren patch.
Bob Allen Bank	6A	25 01.39	80 39.41	0.75 ± 0.08	46	South side of the bank in a grass bed.
Bob Allen Bank	6C	25 01.39	80 39.41	1.08 ± 0.10	79	10 m from 6A in a barren spot.
Rankin Bight	7B	25 09.55	80 47.62	0.33 ± 0.05	28	Northeastern edge of the bight about 100 m from shore.
Lake Ingraham	8B	25 08.85	81 05.88	3.57 ± 0.50	32	West side of central channel in the middle of the lake.
Russell Bank	10B	25 03.84	80 37.52	1.00 ± 0.08	141	Top of the bank ¹ .
Johnson Key Basin	11A	25 03.10	80 54.39	0.37 ± 0.04	5.6	Eastern side of basin in a grass bed.
Porjoe Bank	12B	25 08.04	80 28.42	0.50 ± 0.08	35	Eastern side of the bank in a grass bed.
Porjoe Bank	12D	25 08.04	80 28.42	0.50 ± 0.08	36	Eastern side of the bank in the same grass bed as 12B.
Trout Creek Spit	13D	25 12.55	80 31.99	0.41 ± 0.05	27	Spit on the eastern side of the entrance to Trout Creek.
Little Madeira Bay	14B	25 10.65	80 37.44	0.85 ± 0.09	22	Mouth on the eastern side of Little Madeira Bay.
Crocodile Point	16B	25 08.32	80 43.68	0.33 ± 0.06	85	Transverse north-south bank in grass bed ² .
Pass Key Bank	17D	25 08.86	80 34.49	3.50 ± 0.12	165*	Top of bank in the middle of the old channel.
Pass Key Bank	17G	25 08.86	80 34.49	5.80 ± 0.60	230*	Top of bank, 5 m from 17G in a barren site.
Russell Bank	18B	25 03.98	80 37.46	0.75 ± 0.06	48	Northern side of the bank ³ .
Russell Bank	19B	25 03.83	80 37.48	1.27 ± 0.08	54	South side of bank in deeper water than 10B (grassy).
Russell Bank	19C	25 03.83	80 37.48	0.97 ± 0.08	71	South side of bank 10 m from 19B (barren).
Bob Allen Bank	20D	25 01.39	80 39.41	1.56 ± 0.20	182	South side of bank in a barren "hole" deeper than 6A.
Pass Key Bank	21B	25 08.86	80 34.49	3.00 ± 0.08	462*	Top of bank in the middle of the old channel.
Pass Key Bank	21E	25 09.06	80 34.57	1.78 ± 0.50	119*	Western side of bank, south of old channel.
Pass Key Bank	21F	25 08.83	80 34.21	1.91 ± 0.06	114*	Western side of bank, south of the old channel.
Russell Bank	22D	25 03.88	80 37.55	0.88 ± 0.08	55	Top of bank to the north and west of core site 19.
Park Key	23A	25 06.27	80 34.47	0.78 ± 0.05	25	Northern side of the bank, sparse grass.
Bob Allen Bank	24A	25 01.42	80 33.84	0.78 ± 0.09	25	South side of bank, 1 km southeast of 6.
Bob Allen Bank	24C	25 01.42	80 33.84	0.73 ± 0.08	20	South side of bank, 1 km southeast of 6.
Whipray Basin	25B	25 04.27	80 44.31	0.43 ± 0.07	23	Eastern side of the basin in deeper water than site 5.

¹ The core "Russell Bank 10C" appears to be in three segments: a top part that has either been rapidly deposited or is mixed, a middle part that has the character of a grass bed (a highly variable ^{210}Pb signal and a lot of grass fragments), and a bottom part.

² The top 20 cm are disturbed. The rate of accumulation was calculated for the section of the core below the mixed layer.

³ The top of the core appears to represent material that has "slumped" into place. The rate was calculated using part of this zone.

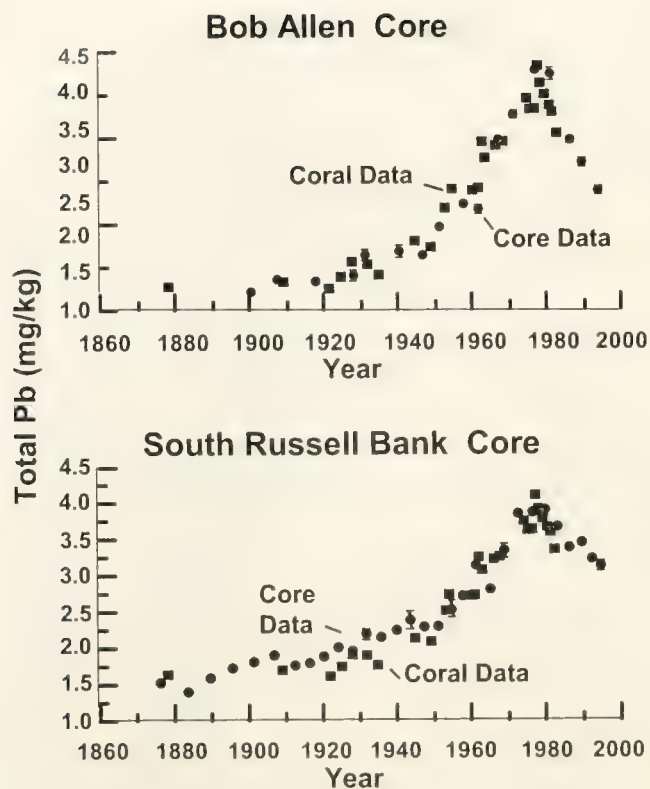
do not attain equilibrium. Age calculations and photographic evidence indicate that the core bottom sediments (~1 m) are less than thirty years old. A summary of the rates of accumulation is given in Table 2.

Confirmation and Replication of ^{210}Pb Ages

Shen and Boyle (1987) measured stable lead concentrations in the annual bands of a *Monastrea annularis* coral collected on the ocean side of the Florida Keys, directly east of this study area. The total stable lead concentration in this coral reached a maximum around 1977, which corresponds to the peak use of leaded gasoline. In three cores, 6A and 6C (Bob Allen Bank) and 19C (S. Russell Bank), the down core profile of stable lead was determined by ICP-MS. These core and coral sites are located less than five miles apart. The stable lead concentrations for both the cores and coral are plotted against time (Text-fig. 5). The ages of the cores were calculated from the ^{210}Pb data, while the age of the coral was determined by counting the annual bands. The clear concordance of these in-

dependently dated profiles confirms the validity and accuracy of our sediment geochronology.

The within-station variability in sedimentation rates was estimated using two cores collected 10 meters apart on Bob Allen Bank (Text-fig. 6). Core 6A was collected in a grass bed, while core 6C was taken in a barren area. Core 6A shows a fairly constant sediment flux prior to 1965 with the minimum accumulation occurring during the mid-1930s. Since 1965, the flux rate has rapidly decreased. In comparison, at the non-vegetated site, the sediment flux fluctuated widely before the 1920's. A distinct decrease in sedimentation occurred in the 1930's, followed by a sharp increase up to 1950. After 1950, the sediment flux has been decreasing steadily. The patterns between the two cores are remarkably similar, suggesting that the same forces control sediment accumulation in both areas, though to slightly different degrees. There is also a difference in bulk density between the two cores. The average density of sediment within the grass bed is 0.7 g/cm^3 , whereas the average density of the sediment at

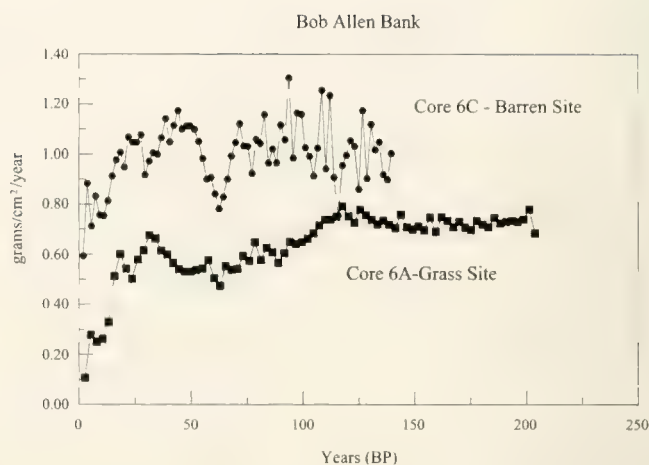


Text-figure 5.—Comparison of the distribution of stable lead with dated cores (6A and 19C) and a dated coral.

the barren site is 0.9 g/cm^3 . The core taken in the grass bed contains a high percentage of plant material, which decreases the overall density of the sediment. A similar comparison can be seen in the Pass Keys Cores—17D and 17G (Text-fig. 7).

Sedimentary Dynamics

As mentioned above, the source of excess ^{210}Pb is a result of the severed decay chain by the gaseous ^{222}Rn . As a result ^{210}Pb can reach a site of deposition via atmospheric fallout or a combination of atmospheric fallout and particle transport in which lead is added along the route of transport. The atmospheric flux along the northeastern coast of the United States has been measured as $1.0 \pm 0.2 \text{ dpm/cm}^2$ (Turekian *et al.*, 1983). This would produce a steady state inventory of excess ^{210}Pb of $32 \pm 6 \text{ dpm/cm}^2$. Similar inventories determined in lowland soil profiles in the eastern United States average $26 \pm 4 \text{ dpm/cm}^2$. Baskaran *et al.* (1993) measured the atmospheric flux at Galveston and College Station, Texas, as varying between 0.67 and $1.71 \text{ dpm/cm}^2/\text{yr}$, with a mean of $1.03 \text{ dpm/cm}^2/\text{yr}$. Their data also demonstrated the flux differences in between continental and marine sources, with the marine sources producing a smaller flux than the continental source. In south Florida a flux of $0.8 \text{ dpm/cm}^2/\text{yr}$



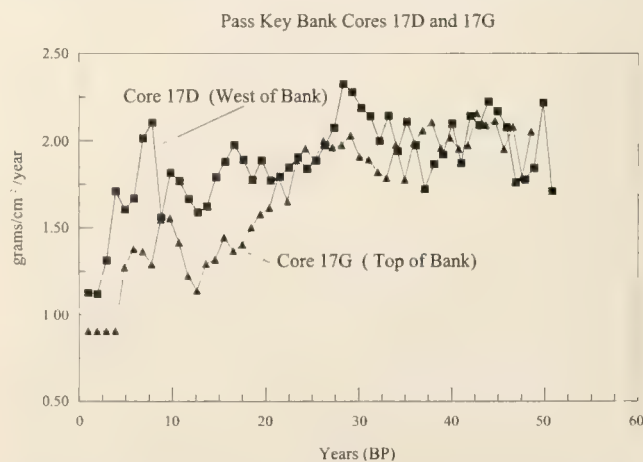
Text-figure 6.—Comparison of sedimentation rates between core 6A (Grass) and 6C (Barren) from Bob Allen Bank. The high variation in sedimentation rates in the barren core (6C) may be related to climate fluctuations (see Cronin *et al.*, this volume).

yr was measured at the University of Miami for the year 1997 by Dr. Frank Millero (written communication, 1998). This would yield an inventory of $\sim 25 \text{ dpm/cm}^2$. Dalphino *et al.* (1993) estimated an inventory of 19 dpm/cm^2 which would suggest an average flux for south Florida of $\sim 0.6 \text{ dpm/cm}^2/\text{yr}$. These lower values are consistent with the proposed marine source of air masses that move across south Florida.

Inventories of excess ^{210}Pb have been calculated for each core from:

$$Q_0 = \sum (\rho_i h_i A_i)$$

where Q_0 = inventory of excess ^{210}Pb , ρ_i = dry bulk density of the i th depth interval ($\text{g}_{\text{dry}}/\text{cm}^3$), h_i = thickness of the i th interval (cm), and A_i = excess ^{210}Pb of the i th interval (dpm/g). The summation of the excess



Text-figure 7.—Comparison of sedimentation rates between core 17D and 17G from Pass Key. The difference in sedimentation rates can be attributed to their relative locations to the central channel.

values was carried out from the surface to that level in which the difference between background and excess ^{210}Pb activity was indistinguishable. The inventories record in the cores ranges from 3 dpm/cm² to >400 dpm/cm². Assuming that the excess ^{210}Pb inventory should be in the 20 to 30 range if all of the lead was a result of atmospheric flux, these extreme values lead to some indications of the sediment dynamics. The inventories are presented in Table 2. Those sites with inventories significantly lower than can be accounted by the atmospheric flux indicate that some sediment has been removed. The three such sites are on the southern and western sides of the Bay. In Whipray basin, the core with the lowest inventory (5G) is much shallower than core 25. The ^{210}Pb distribution curve in this core has an apparent discontinuity at about 16 cm hinting at an interval of missing sediment. Along the northern fringe of the bay, the inventory in cores 7, 13, 14 and 16 imply that the source of lead was wholly atmospheric. At all the rest of the sites, the high inventories are indicative of sediment ^{210}Pb "enriched" by focusing and/or an external non-atmospheric source, possibly ground-water fluxes. In general, the highest inventories were measured on Pass Key bank, where the highest rate of sediment accumulation occurs forming the bank within the last 30 years. The high rate on Bob Allen Bank (core 20) was measured at a site in deeper water further south than

the other cores, consistent with the idea of southward accretion of the banks.

SUMMARY

The determination of sediment geochronologies using ^{210}Pb at various sites within the sedimentary banks of Florida Bay has yielded a valid time scale on the order of decades. These calculated ages have been confirmed by independent means. At sites in the western portion and along the northern fringe of the Bay, sediment accumulation is ~0.3 cm/yr. At sites in the western part of the Bay, the inventory of ^{210}Pb is much less than atmospheric flux, indicating that sediment has been removed, probably by storms. In the northeastern section of the Bay, which is most impacted by changing salinity regimes, the sedimentation rates vary from 0.7 cm/yr to greater than 2.0 cm/yr. In the central part of the study area on the leeward side of Russell Bank and Bob Allen Bank, the sediment accumulation rate is moderate (~1.0 cm/yr). It is from these sites that the ecological history of Florida Bay during the last century could best be developed. Additional ongoing studies are addressing other geochemical and paleontological issues (Cronin *et al.*, 1998). This investigation on the feasibility of dating the sediments in Florida Bay has proven to be quite successful; the information is being used to reconstruct the paleoecological history of the bay and to assess the transport and deposition of Florida Bay sediments.

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CHAPTER 4

THE FLORIDA EVERGLADES ECOSYSTEM: CLIMATIC AND ANTHROPOGENIC IMPACTS OVER THE LAST TWO MILLENNIA

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ABSTRACT

We document the response of the Everglades ecosystem to climatic and environmental changes over the last two millennia using pollen records. Centennial-scale intervals of vegetational stasis characterize the time between 0 A.D. and 1900 A.D. From 0–800 A.D., marsh and slough vegetation characteristic of deeper water and longer hydroperiods (annual duration of inundation) than today dominated the study region. Drier conditions between about 800 A.D. and 1200 A.D. resulted in shallower water depths and shorter, fluctuating hydroperiods in Everglades marshes as well as salinity increases near Florida Bay. After a recovery to deep-water conditions in the 14th century, somewhat drier conditions are suggested between the 17th and 19th centuries. These climatically-induced periods of relative dryness are correlated with regional droughts during the intervals known as the Medieval Warm Period (9th–14th centuries) and Little Ice Age (15th–19th centuries).

Although regional precipitation was greater than average after 1920 A.D., vegetational changes throughout the area indicate reduced water depths and hydroperiods after construction of water-control structures in the early 20th century. Further, more localized changes occurred after 1960, when the Central & South Florida (C&SF) Project was completed. Thus, restoration goals of achieving pre-C&SF Project hydrologic regimes are aimed at an already disrupted system; a more “natural” restoration target would be the 19th century Everglades, which had been stable for the past few centuries. Recent land-use changes have resulted in localized rather than system-wide ecosystem responses, at least in part because of the fragmentation of the wetland. This artificially induced ecological heterogeneity makes prediction of future wetland responses to climatic changes problematic.

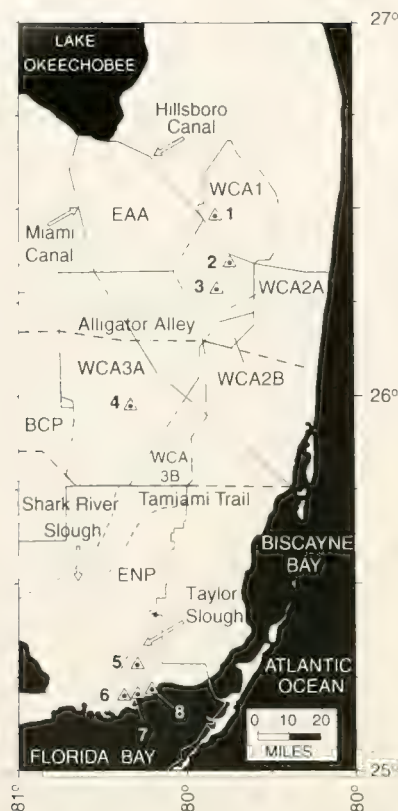
INTRODUCTION

In wetland ecosystems, climatic warming is expected to cause lowered water tables, increased rates of evapotranspiration, and, in the Florida Everglades, greater incidence of saltwater intrusion from both sea-level rise and hydrologic changes (Watson *et al.*, 1996). Additionally, anthropogenic changes in hydrology and nutrient availability due to land-use alterations affect wetland ecosystems on both local and regional scales. The accurate prediction of wetland response to future climatic and environmental changes is hampered by a lack of broad-scale, long-term studies of past changes in wetland ecosystems. Such studies are feasible in the Florida Everglades, where we have collected a series of cores that preserve records of the last 2,000 to 3,000 years of Everglades vegetation (Text-fig. 1). These cores provide data on past responses of wetland vegetation to late Holocene climatic events as well as hydrologic alteration of the system over the last century. A possible analog for Everglades response to a predicted warming of 1°C to 3.5°C by 2100 A.D. (Watson *et al.*, 1996) is preserved in sediments deposited during the Medieval Warm Period (MWP)

(800–1300 A.D.) (Hughes and Diaz, 1994) when sea-surface temperatures at least 1°C warmer than today have been documented in the Sargasso Sea (Keigwin, 1996). The impact of a cooling event, the Little Ice Age (LIA) (A.D. 1550–1850) (Bradley and Jones, 1993) on Everglades vegetation also is preserved in many cores throughout the region. Of particular interest are the timing and extent of vegetational changes in response to hydrologic changes and changing land-use practices of the last century. This suite of cores provides the temporal and spatial coverage necessary to address these questions on a regional basis.

Vegetational distribution in the Everglades wetland is controlled primarily by water depth, hydroperiod (average annual length of inundation), substrate, fire regime, and water chemistry (Kushlan, 1990). Although plant community composition can vary locally, several broad vegetational categories have been identified (Davis *et al.*, 1994; McVoy *et al.*, 2000; Willard *et al.*, 2001a). These include: the Ridge and Slough region consisting of a mosaic of sawgrass-dominated marshes, sloughs, and tree islands in the north and central Everglades and ranging southwest through the Shark River Slough; sparse sawgrass marshes and wet prairies in the southern Everglades; cypress swamps

³ Deceased.



Text-figure 1.—Map of core locations discussed in this study. Detailed locality information is provided in Table 1.

and domes and pinelands in the Everglades and Big Cypress National Preserve; and mangrove forests along the Florida Bay and Whitewater Bay coasts (Text-fig. 2). This report presents reconstructions of the vegetational history of the Everglades ecosystem at several sites over the last two millennia and its response to both natural climatic fluctuations and altered land-use practices of the last century.

ACKNOWLEDGMENTS

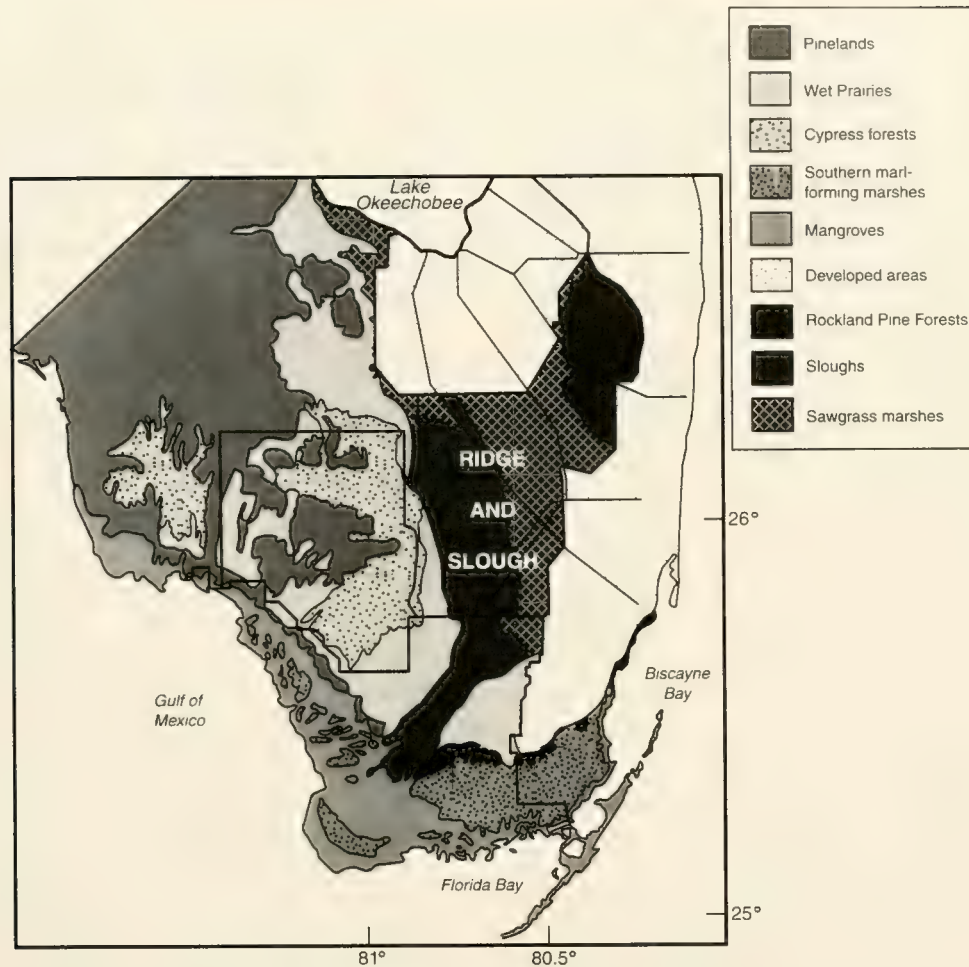
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STUDY SITES AND METHODS

Peats preserved in the historic Everglades provide a detailed archive of biotic patterns over the last few millennia. Cores discussed herein were collected in Water Conservation Areas 1, 2, and 3, in Taylor Slough, and in the dwarf mangrove fringe adjacent to Florida Bay (Text-fig. 1, Table 1). These sites were selected to evaluate past vegetational patterns in the Ridge and Slough area, where relatively minor changes in hydroperiod and water depth may alter the spatial distribution of vegetation types, and in the saline-influenced part of the Everglades, where hydrologic changes may result in salt-water intrusion.

Pollen assemblages and geochronology were analyzed from samples collected at 1–2 cm intervals throughout the cores. Most cores are about 0.7 meters long, cover the last two millennia (Tables 1, 2), and reach the underlying Pleistocene limestone. Age models for the last century of deposition are based on ^{210}Pb , ^{137}Cs , and ^{14}C from atomic testing (Robbins *et al.*, 2000) and, where applicable, first occurrences of pollen of the exotic plant *Casuarina* which was introduced to south Florida in the late 19th century (Landeland, 1990). In older sediments, models are derived from linear interpolation between radiocarbon data points (Table 2), which were calibrated to calendar years using the Pretoria Calibration Procedure (Stuiver *et al.*, 1993; Talma and Vogel, 1993; Vogel *et al.*, 1993). In cores where both bulk radiocarbon dates and AMS dates on plant fragments were obtained, age models are based on the AMS dates, which minimize the possibility of contamination by sediments outside the sample interval. Pollen was isolated from samples using standard palynological techniques (Traverse, 1988), including carbonate and silicate removal with HCl and HF when necessary, acetolysis to reduce the amount of phytodebris, sieving through 8 μm mesh to remove clay-size particles, heavy liquid treatment when needed, and staining with Bismarck Brown before mounting on microscope slides with glycerin jelly. Tablets with known numbers of *Lycopodium* spores also were added to the dry samples for determination of pollen/gram dry sediment (see (Maher, 1981). To calculate percent abundance in each sample, at least 300 pollen grains were identified and counted. In some cases, pollen preservation was poor, and counts of at least 100 grains were included in the analyses. Pollen data and closest analogs are available via the internet



Text-figure 2.—Generalized map of vegetation types, developed areas (urban and agricultural), and boundaries of Water Conservation Areas, Big Cypress National Preserve, Everglades National Park, and Loxahatchee National Wildlife Refuge. Compiled from Davis (1943) and Davis *et al.* (1994).

from the North American Pollen Database (NAPD) at the World Data Center for Paleoclimatology in Boulder, CO (<http://www.ngdc.noaa.gov/paleo/pollen.html>) and at the US Geological Survey South Florida Ecosystem History Database at <http://flaecoehist.er.usgs.gov/database>.

We interpreted vegetational changes in cores from

patterns in both percent abundance and concentration (pollen/gram dry sediment) of pollen. The timing of major vegetational changes is clear from examination of pollen diagrams. However, to improve the accuracy of vegetational interpretations based on pollen data, we statistically compared assemblages from cores to those from modern samples using both cluster analysis and

Table 1.—Site locations, core length, and date of core collection for sediment cores, South Florida.

Site	Latitude (N)	Longitude (W)	General location	Core length (cm)	Date collected
1	26°28.873'	80°24.931'	Loxahatchee NWR	72	4/21/1995
2	26°21.580'	80°22.230'	Water Conservation Area 2A	72	4/26/1995
3	26°17.254'	80°24.660'	Water Conservation Area 2A	71	4/25/1995
4	25°58.455'	80°40.129'	Water Conservation Area 3A	70	4/27/1995
5	25°17.231'	80°38.780'	Taylor Slough	76	5/20/1996
6	25°12.111'	80°41.227'	Taylor Slough	78	5/24/1996
7	25°12.339'	80°38.641'	Everglades National Park	86	3/29/1995
8	25°13.190'	80°36.279'	Everglades National Park	82	3/15/1996

Table 2.—Radiocarbon dates from peat cores, South Florida.

Site	Depth (cm)	Beta no.	Sample type	$^{13}\text{C}/^{12}\text{C}$ ratio	Corrected ^{14}C age (BP)	Calendar age
1	30–32	110295	Bulk	–26.2	480 $\pm$ 40	AD 1410–1470
1	50–52	110296	Bulk	–27.4	960 $\pm$ 40	AD 1005–1180
1	70–72	110297	Bulk	–26.2	1590 $\pm$ 40	AD 405–575
2	14–16	104814	AMS—leaf	–21.6	175.2% $\pm$ 0.4	post 1950
2	28–30	104815	AMS—leaf	–16.7	1040 $\pm$ 50	AD 860–960
2	32–36	90032	Bulk	–26.3	1090 $\pm$ 60	AD 800–920
2	40–42	104816	AMS—leaf	–16.8	1910 $\pm$ 50	10 BC–AD 90
2	52–56	90033	Bulk	–26.3	1990 $\pm$ 60	100 BC–AD 20
2	60–64	90034	Bulk	–26.1	2270 $\pm$ 60	380–260 BC
3	26–28	129850	Bulk	–27.1	400 $\pm$ 50	AD 1425–1635
3	38–40	129849	Bulk	–27.4	930 $\pm$ 50	AD 1005–1220
3	50–52	129848	Bulk	–27.4	1700 $\pm$ 50	AD 235–435
3	64–68	90034	Bulk	–26.6	2090 $\pm$ 60	
4	30–32	110292	Bulk	–25.6	610 $\pm$ 40	AD 1295–1420
4	50–52	110293	Bulk	–25.9	1880 $\pm$ 40	AD 65–240
4	64–68	110294	Bulk	–25.1	2470 $\pm$ 40	BC 780–405
5	30–32	110298	Bulk	–25.5	1500 $\pm$ 40	AD 465–645
5	50–52	110299	Bulk	–23.3	2460 $\pm$ 40	BC 780–405
5	72–74	110300	Bulk	–23.8	3560 $\pm$ 40	BC 1975–1760
6	30–32	115197	AMS—leaf	–27.0	310 $\pm$ 40	AD 1600–1680
6	44–46	114967	Bulk	–26.8	320 $\pm$ 50	AD 1580–1680
6	60–62	115644	AMS—leaf	–30.6	530 $\pm$ 60	AD 1305–1460
7	0–4	104507	AMS—twig	–27.6	109.8% $\pm$ 0.6	post 1950
7	4–8	104508	AMS—twig	–26.5	96.0% $\pm$ 0.4	post 1950
7	13–14	86194	Bulk	–27.4	370 $\pm$ 60	AD 1520–1640
7	20–24	104510	AMS—twig	–26.8	230 $\pm$ 40	AD 1680–1760
7	24–26	96195	Bulk	–27.3	700 $\pm$ 70	AD 1180–1320
7	75–76	86785	Bulk	–26.5	1610 $\pm$ 60	AD 280–400
8	30–32	96610	Bulk	–27*	300 $\pm$ 80	AD 1570–1730
8	58–60	93311	Bulk	–27*	750 $\pm$ 80	AD 1120–1280
8	78–84	93312	Bulk	–27*	1950 $\pm$ 70	70 BC–AD 70

Note: Site numbers correspond to sites in Figure 1. Radiocarbon dating was performed by Beta Analytic, Miami, Florida, dating both bulk sediment and selected plant fragments with AMS. When aerial material could not be separated confidently from the peat, homogenized bulk samples were used. Due to the possibility of contamination by younger roots, dates on bulk samples represent minimum ages for the intervals. Corrected dates are based on fractionation calculated by $\delta^{13}\text{C}$. Calendar ages have been calibrated according to Stuiver *et al.*, 1993, Talma and Vogel, 1993, and Vogel *et al.*, 1993, $\pm 2\sigma$, and 95% probability.

These $\text{C}13/\text{C}12$ ratios were not determined but are estimates based on the peat composition.

the modern analog technique. Cluster analysis and other hierarchical classification techniques are used to show relationships among different samples based on species abundance in those samples. These relationships are determined by first calculating a sample-by-sample distance matrix and then linking samples into clusters based on their dissimilarity/similarity to each other (Gauch, 1982). We used average-linkage clustering (UPGMA) with the Pearson product moment correlation coefficient and the computer program MVSP 3.1 (Kovach, 1999) to cluster our samples.

The modern analog technique compares fossil pollen assemblages with modern assemblages from a number of vegetation types to identify the closest modern analog (Overpeck *et al.*, 1985). If close analogs exist for the fossil assemblage, it is assumed to have a similar vegetational composition and, by extension, similar environmental parameters, such as hydroperiod or water depth. Modern analogs are identified by cal-

culating a dissimilarity coefficient between a fossil and modern assemblage; samples with dissimilarity coefficients less than a critical value are considered to represent the same vegetation type. To determine the appropriate critical value for these samples, we calculated dissimilarity coefficients (using squared chord distance, or SCD) among all modern samples using the ANALOG program of Schweitzer (1994) (see Willard *et al.*, 2001a). Samples from the same vegetation type typically had SCD values <0.15 . Recognizable wetland subenvironments include sloughs, sawgrass marshes, sawgrass marshes near tree islands, southern Everglades sawgrass marshes/wet prairies, tree islands, southwestern mangrove forests, and cattail marshes. This modern dataset incorporates both samples collected between 1995 and 1998 and samples collected in the early 1960s. The latter group includes a number of sites that have since been altered by construction of the Central & South Florida (C&SF) Project since

Table 3.—Clusters from Q-mode cluster analysis of modern and fossil pollen assemblages, modern analogs, and pollen signatures for each cluster.

Cluster	Modern analog	Pollen signature
I	TREE ISLANDS	Fern Spores > 25%
II	LOXAHATCHEE SAWGRASS MARSHES	<i>Myrica</i> > 30%
III	SOUTHWESTERN MANGROVE FORESTS AND BRACKISH MARSHES	<i>Rhizophora</i> > 15%; <i>Avicennia</i> and <i>Conocarpus</i> present
IV	SOUTHERN EVERGLADES MARSHES AND SLOUGHS	
IV a	No modern analogs, but apparently fresh-water marshes	Cyperaceae 22–32%; <i>Myrica</i> 18–30%
IV b	Wet Prairies (no fossils)	<i>Myrica</i> 5–20%; Asteraceae > 15%; Sum of Cyperaceae and <i>Sagittaria</i> > 5%
IV c	Dwarf Mangrove Stands	<i>Rhizophora</i> 5–25%; <i>Myrica</i> 2–12%; Cyperaceae 1–5%
IV d1	Wet Prairies, Cypress Stands, Pinelands	<i>Pinus</i> > 40%; <i>Myrica</i> 5–12%; Asteraceae > 5%; Cyperaceae > 2%
IV d2	Sawgrass marshes	<i>Pinus</i> 20–40%; <i>Myrica</i> > 15%; Asteraceae 3–10%; Cyperaceae > 3%
V	NORTHERN EVERGLADES MARSHES AND SLOUGHS	
V a	Dense Sawgrass Marshes	Cyperaceae > 10%; Asteraceae > 10%; <i>Sagittaria</i> > 5%
V b1	Sloughs (primarily fossils)	<i>Nymphaea</i> 5–20%; sum of Cyperaceae and <i>Sagittaria</i> > 5%
V b2	Sloughs, Dense Sawgrass Marsh	Cheno/Ams 30–40%; sum of <i>Nymphaea</i> , <i>Sagittaria</i> , and Cyperaceae > 10%
V c	Sawgrass Marshes near Tree Islands or Disturbed Sites	Cheno/Ams > 40%; sum of <i>Typha</i> , Cyperaceae, and <i>Sagittaria</i> > 10%

1960, and they include deeper water sloughs than occur today.

ECOLOGY AND POLLEN SIGNATURES OF EVERGLADES VEGETATION TYPES

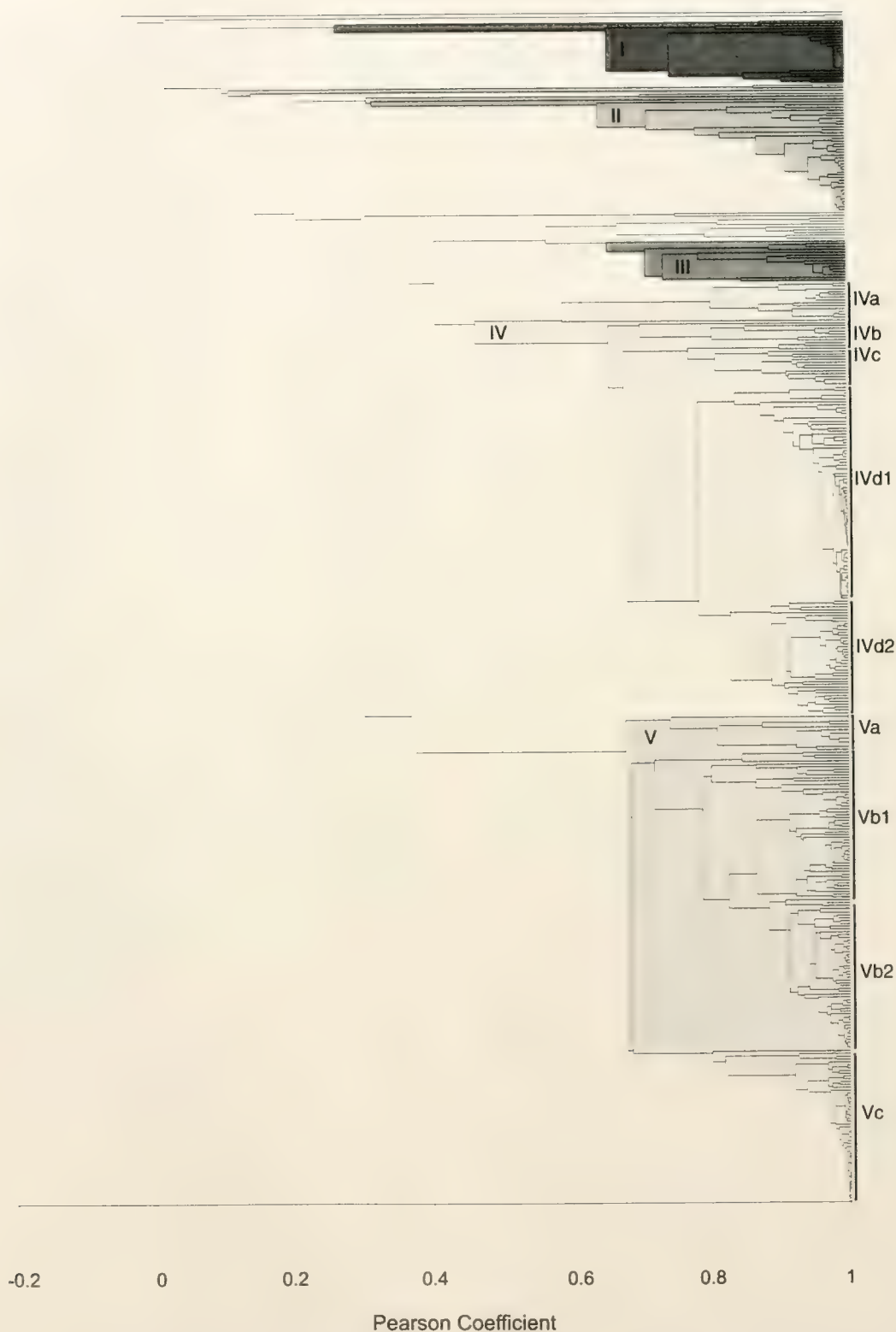
Eight vegetation types are clearly distinguishable from modern pollen assemblages collected throughout the Everglades (Willard *et al.*, 2001a). Slough vegetation occurs in the wettest sites and typically is dominated by floating aquatics such as *Nymphaea* (water lily) and *Utricularia* (bladderwort). This community type grows in relatively deep water over thick peat substrates and requires long hydroperiods (>9 months annual inundation) (Kushlan, 1990). Pollen assemblages from sloughs are distinguished by >3% *Nymphaea* pollen (Willard *et al.*, 2001a) and include samples in cluster Vb (Table 3, Text-fig. 3).

Marshes requiring moderate water depths (<1 meter) and hydroperiods (6–9 months annual inundation) include those dominated by *Cladium* (sawgrass), *Sagittaria* (arrowhead), *Eleocharis* (spikerush), and *Typha* (cattail). Substrate type, fire frequency, nutrient content of surface waters, and disturbance determine the dominant component (Kushlan, 1990). Sawgrass marshes consist primarily of *Cladium*, grading into flag marshes with more *Sagittaria* and *Eleocharis* where surface sediments change from deeply organic peats to shallow peats and marls (Kushlan, 1990). Pollen assemblages from typical sawgrass marshes are dominated by *Cladium* and *Sagittaria* pollen and are represented in clusters Va and Vb2 (Table 3). Cattail

marshes, dominated by *Typha*, may replace sawgrass marshes after disturbances, such as severe fires or nutrient enrichment (Davis, 1994). Sawgrass marshes near tree islands, near levees and canals, and with fluctuating water levels are dominated by pollen of weedy annuals, particularly *Amaranthus* (water hemp) or the Asteraceae (aster family) (Willard *et al.*, 2001a). These plants are known to become particularly abundant after periods of rapid drying over a few (<5) years or prolonged droughts (Loveless, 1950; McVoy *et al.*, 2000). Pollen assemblages from both cattail marshes and sawgrass marshes associated with tree islands or disturbance are included in cluster Vc (Table 3).

Short hydroperiod marshes such as wet prairies require shallow water depths, seasonal drying (0–3 months annual inundation), and either marl or shallow peat substrates (Kushlan, 1990). Sparse vegetation in these marshes consists primarily of taxa in the Poaceae (grass family) and Cyperaceae (sedge family) that tolerate both dry and flooded conditions. These marshes, most common in the southern Everglades, have the greatest abundance of *Myrica* (wax myrtle) pollen, as well as Poaceae and Cyperaceae (Willard *et al.*, 2001a); wet prairies are represented in clusters IVb and IVd (Text-fig. 3, Table 3). *Pinus* pollen also is abundant in these assemblages; however, it represents extra-local deposition and reflects low pollen productivity of plants in this community type.

Tree islands are interspersed throughout the marshes and sloughs of the Everglades, and two types exist. “Pop-up” or battery islands, dominated by bays (*Per-*



Text-figure 3.—Dendrogram from Q-mode cluster analysis (using UPGMA and Pearson correlation coefficient) of pollen assemblages from surface samples and down-core samples from sites 1–8, Florida Everglades. Cluster I represents tree-island samples. Cluster II represents samples from sawgrass marshes in Loxahatchee NWR. Cluster III includes samples from southwestern mangrove forests and brackish marshes. Cluster IV includes samples from southern Everglades marshes and sloughs. Cluster V includes samples from northern Everglades marshes and sloughs. Finer details on clusters are provided in Table 3.

sea) and holly (*Ilex*), are the most common type in Loxahatchee National Wildlife Refuge; these sites are characterized by abundant *Ilex* and *Myrica* pollen and are included in cluster II (Table 3). Fixed, tear-drop shaped tree islands, which are elongated parallel to flow, occur throughout the Everglades; vegetation on tree island heads consists of trees, shrubs, and ferns and the tapering tails are vegetated by shrubs, ferns and thick *Cladium* or *Typha*. Pollen assemblages from fixed tree islands are characterized by high abundances of fern spores and are represented in cluster I (Table 3). The high abundance of ferns is a local signature of the tree islands themselves, with fern spores rare in marshes and sloughs surrounding the islands (Willard, *et al.*, 2001b).

Two types of mangrove assemblages occur in South Florida: dwarf mangroves consisting primarily of short (<3 meters) *Rhizophora* near Florida Bay, and the tall, diverse forests near Whitewater Bay in Shark River Slough. Both types are distinguished in the pollen record by abundant mangrove pollen, particularly that of *Rhizophora*. Near Florida Bay, mangrove pollen comprises only about 20% of assemblages and consists primarily of *Rhizophora* with minor amounts of *Conocarpus* and rare *Avicennia* and *Laguncularia*. These are included in cluster IVc (Table 3). In southwestern Florida, however, *Rhizophora* is the dominant element, and the four mangrove genera listed above combine to make up at least 40% of the assemblages (Riegel, 1965; Willard *et al.*, 2001a). These samples comprise most of cluster III (Table 3).

VEGETATIONAL HISTORY: RIDGE AND SLOUGH SITES

PRE-20TH CENTURY VEGETATION

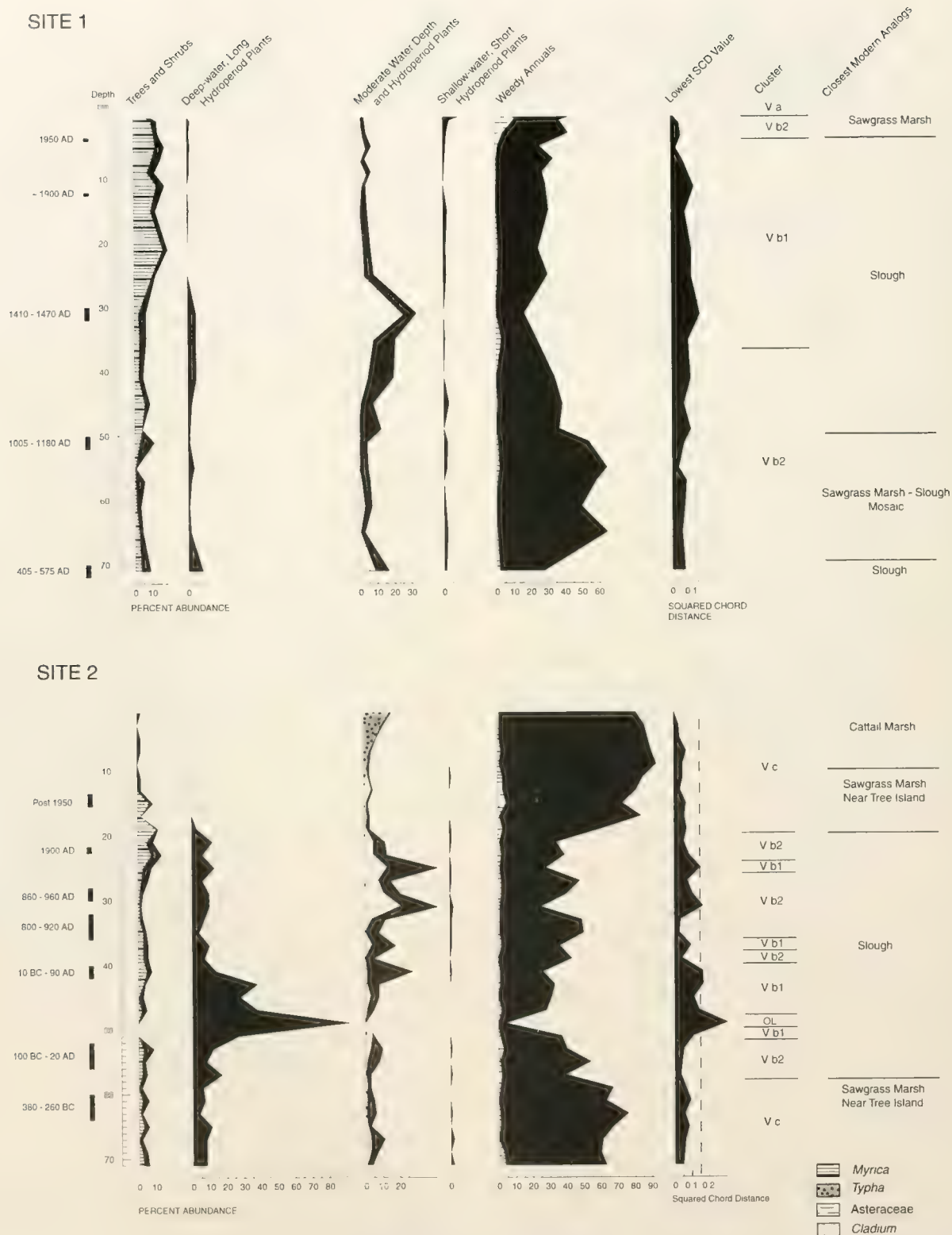
Four cores (sites 1–4; Text-fig. 1) in the Ridge and Slough region (Text-fig. 2) provide records of the last two millennia. From about 0–800 A.D., pollen evidence from these sites indicate that they typically were dominated by slough vegetation, indicating long hydroperiods and relatively deep water (Text-fig. 4). Between 800 A.D. and 1200 A.D., all sites show evidence for shallower water and shorter hydroperiods, although temporal resolution varies among the cores. At sites 1 and 4, comparison with modern analogs indicates that sawgrass marshes replaced sloughs for varying intervals between 800 and 1200 A.D. The great abundance of weedy annuals such as *Amaranthus* at site 4 and, to a lesser extent site 2, indicate that droughts or intervals of rapid drying (over <5 years) (Loveless, 1950; McVoy *et al.*, 2001) occurred during that time, allowing weedy species to flourish. At site 2, *Cladium* pollen abundance increased and samples

are grouped in cluster Vb2, indicating shorter hydroperiods and/or shallower water depths than before. During this interval at site 3, there are no close analogs, but samples cluster with marsh and slough samples from the southern Everglades (Text-fig. 4), where water depths are shallower and peat substrates thinner. Although this is suggestive of drier conditions, the high percentages of *Nymphaea* make confident interpretation of hydrology problematic at this site. Between 1200 A.D. and 1600 A.D., deeper water conditions associated with slough vegetation returned at all four sites, although site 3 remained similar to southern Everglades sloughs. Early in the 17th century, *Myrica* pollen doubled in abundance at all four sites, and *Nymphaea* pollen decreased in abundance at most sites. Although the assemblages remained analogous to sloughs, the increased abundance of tree pollen is suggestive of drier conditions beginning in the early 17th century. Vegetational composition remained stable from then until the early 20th century.

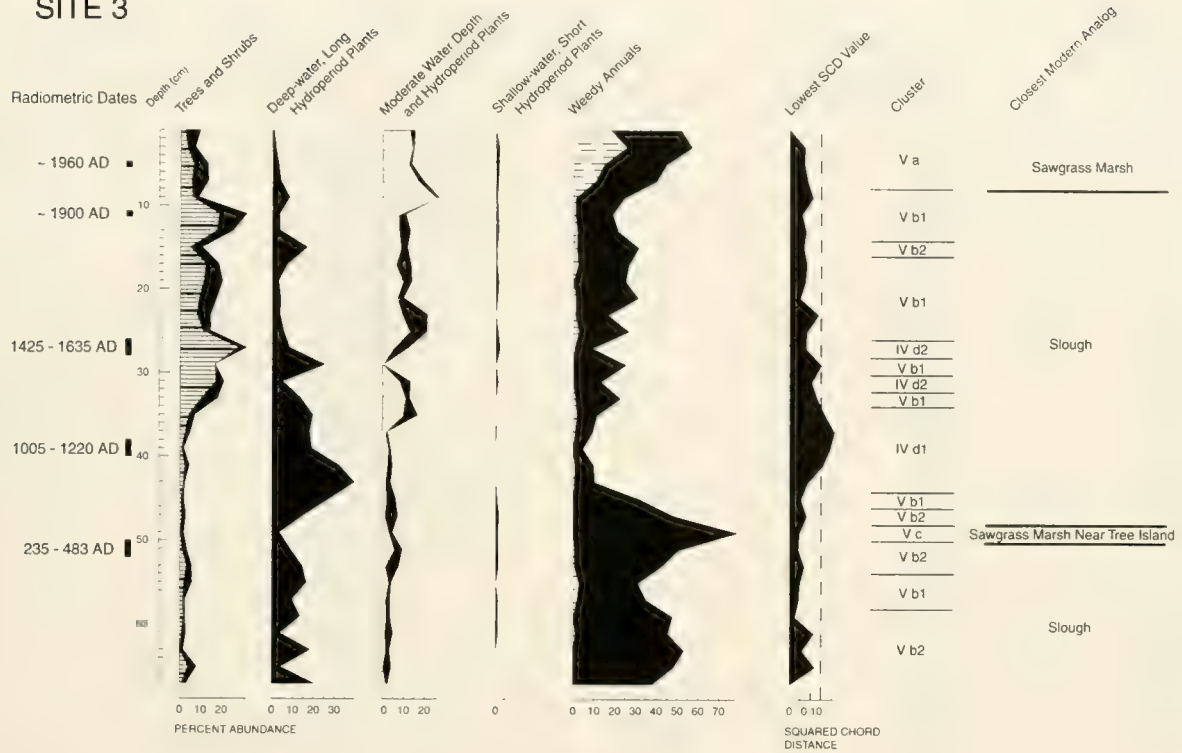
20TH CENTURY VEGETATION

From about 1200 A.D. to 1930 A.D., vegetation at all four sites was characteristic of sloughs. After 1930, however, shallower water conditions are indicated at sites 2, 3, and 4 by the change to sawgrass marshes with abundant weedy annuals. Although shallower water depths are suggestive of drier conditions, precipitation levels were higher than the 20th century average during this time (Text-fig. 5), indicating that reduced water levels and drier marsh conditions at these sites resulted from hydrologic alteration of the system rather than climatic change. Hydrologic changes that were completed by 1930 include construction of the Hoover Dike on the south side of Lake Okeechobee and dredging of major muck canals linking the lake to the Atlantic Ocean (Light and Dineen, 1994). Construction of the Hoover Dike prevented seasonal influx of water to the Everglades from overflow of the southern lake bank, a major source of water for sheet flow across the Everglades. Additionally, substantial areas of the Everglades were drained as the muck canals diverted much of the remaining sheet flow from the Everglades to the ocean.

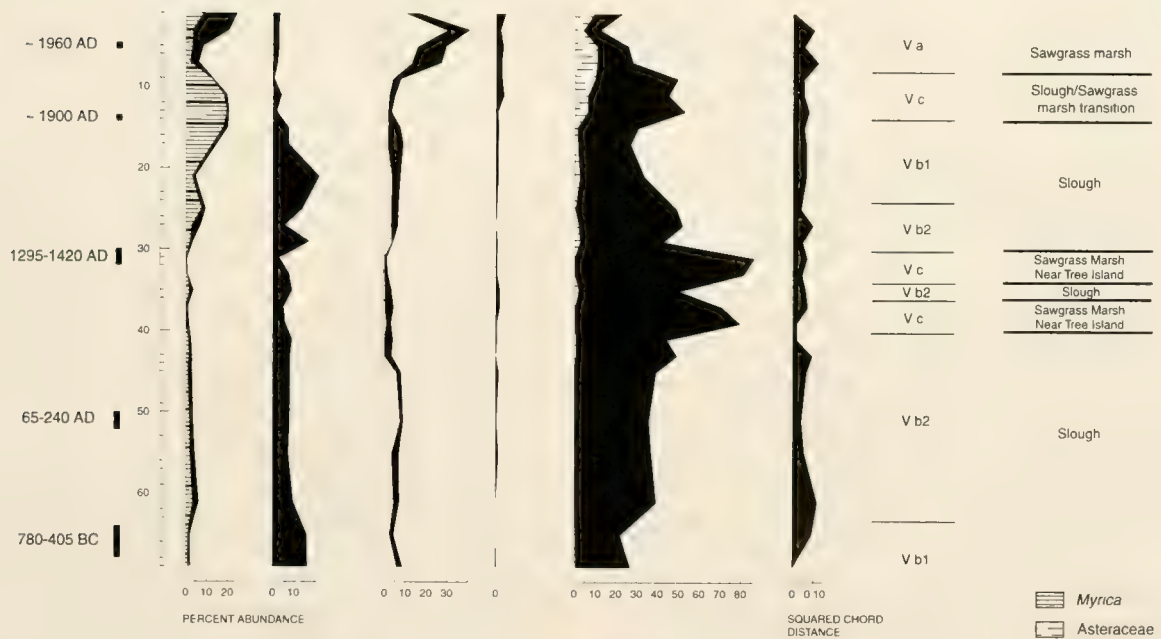
Additional changes occurred between 1950 and 1960. At site 1 in WCA 1, vegetation changed from sloughs to sawgrass marshes; at site 2 near the Hillsboro Canal in WCA 2A, cattail marshes began to dominate the vegetation after 1960. Both changes occurred after completion of the Water Conservation Areas and Everglades Agricultural Area (EAA), part of the C&SF Project. Construction of a levee on the western border of WCA 1 between 1954 and 1959 effectively stopped the remaining sheet flow across WCA 1 (Light



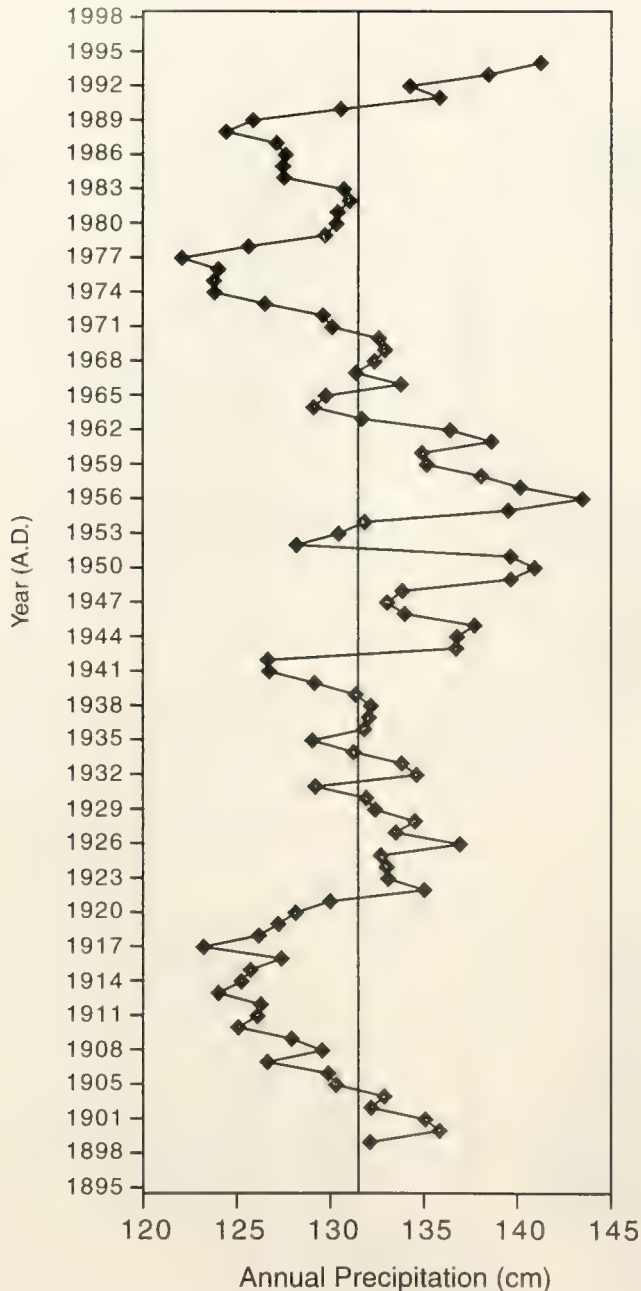
SITE 3



SITE 4



Text-figure 4.—Continued.



Text-figure 5.—Annual rainfall (9 point smoothing) for Everglades, 1895–1998. Vertical line indicates 1895–1998 average. Based on precipitation data for Florida region 5 obtained from NOAA at <http://www.ncdc.noaa.gov/onlineprod/drought/xmgr.html>.

and Dineen, 1994), and the reduced water depths recorded in sediments from site 1 after 1960 illustrates the impact of that hydrologic change. The increased abundance of cattail pollen at site 2 after 1960 is correlated with increased levels of phosphorus in both sediments and pore water from cores (Orem *et al.*, 1999). After 1960, agricultural activities in the EAA expanded rapidly; the subsequent increased phospho-

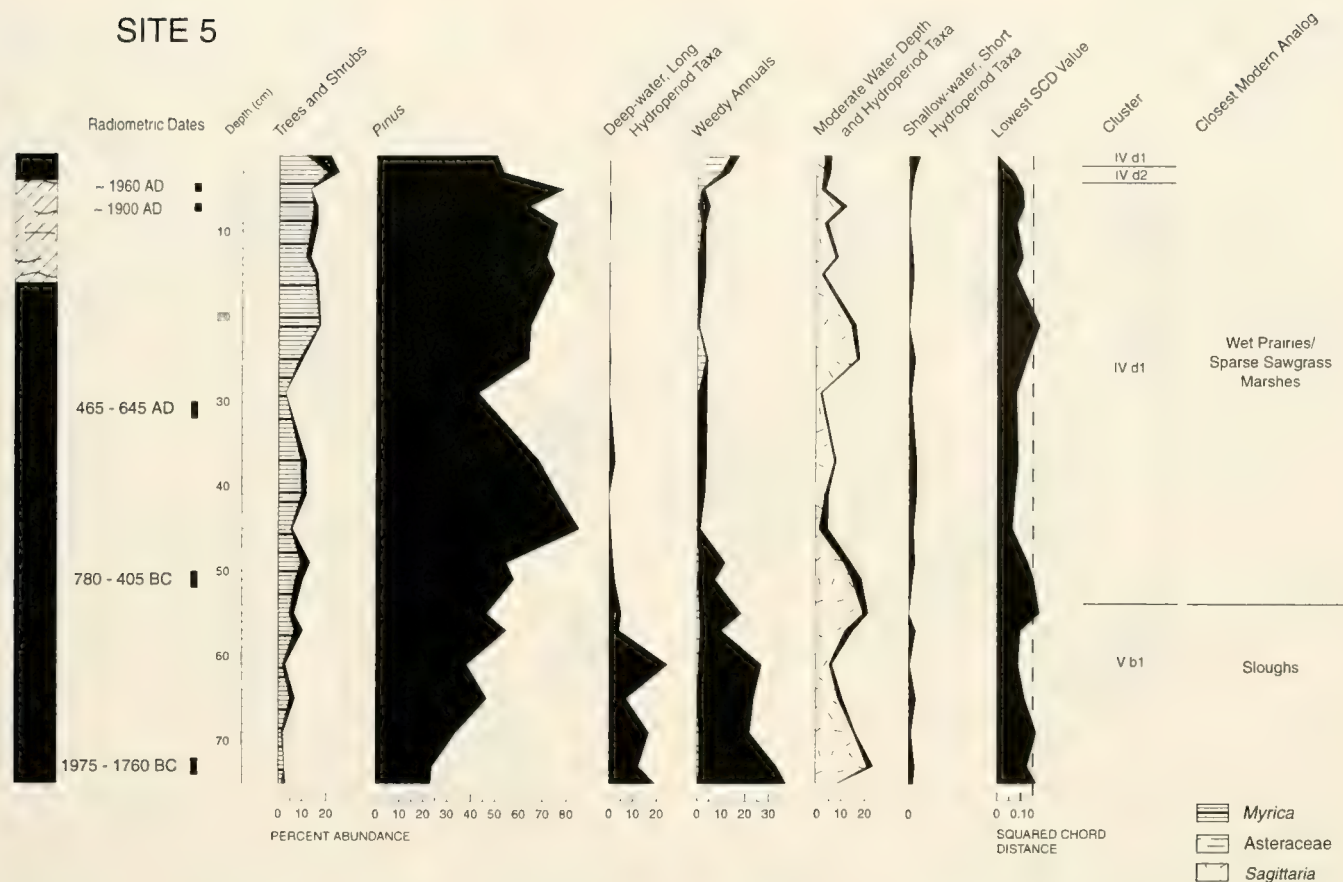
rus concentrations and cattail abundance recorded in sediments at site 2 appears to be tied to greater nutrient runoff from the EAA after that time.

VEGETATIONAL HISTORY: SOUTHERN EVERGLADES SITES

PRE-20TH CENTURY VEGETATION

The impact of climatic changes on hydrology and salinity in the southern Everglades is illustrated in four cores collected in Taylor Slough and near Florida Bay (Sites 5–8, Text-fig. 1). From about 0 A.D. to 1200 A.D., fresh-water marshes, analogous to sawgrass marshes and wet prairies found in the southern Everglades today, dominated the four sites (Text-figs. 6–9). Even at the southernmost site near Florida Bay (site 8), mollusc assemblages of this interval consist exclusively of terrestrial and fresh-water taxa (Text-fig. 9). The first occurrence of brackish mollusc and benthic foraminifer taxa there in the late 13th century coincides with a decreased abundance of pollen typical of fresh-water marshes. By the 16th century, vegetation at that site fluctuated between wet prairies and brackish marshes, indicating periodically shallower water and, possibly, salt-water intrusion. The last occurrence of terrestrial and fresh-water molluscs and algae was in the 17th–18th century, indicating minimal fresh-water influence after that time. Marsh vegetation persisted at this site until late 19th or early 20th century, when mangroves became the dominant element of the vegetation.

Pollen assemblages from site 5, located in very thick peats in the central part of Taylor Slough, indicate changes from sloughs and deep-water conditions to wet prairies/sawgrass marshes with moderate water depths at about 2,800 yrBP (Text-fig. 6). Although sedimentation rates were very low at this site, little vegetational variation is recorded at this site from 2,800 yrBP until the 20th century. Sites 6 and 7 provide little data on vegetational trends prior to about 1300 A.D. because the basal age of the core at site 6 is about 1200 A.D. and because 5–10 cm thick intervals were analyzed for the lower 60 cm of the core collected at site 7. At site 6, pollen assemblages indicate fluctuating hydrologic conditions from about 1300 A.D. to 1900 A.D., with vegetation ranging from wet prairies to brackish marshes to sawgrass marshes, sloughs, and mangroves (Text-fig. 7). Conditions appear to have been less variable at site 7 during that time (Text-fig. 8), although slower sedimentation rates decrease the time resolution possible in that interval. As seen at northern Everglades sites, *Myrica* abundance doubled in the 17th century, possibly indicating regionally drier conditions. From the 17th through 19th centuries, vegetation at all four sites varied little.



Text-figure 6.—Percent abundance of pollen of major plant groups at site 5, central Taylor Slough. SCD values show lowest squared chord distance values for modern analogs; SCD < 0.15 are considered to be close analogs for fossil assemblages. Cluster designations refer to clusters designated in Text-figure 3 and Table 3.

20TH CENTURY VEGETATION

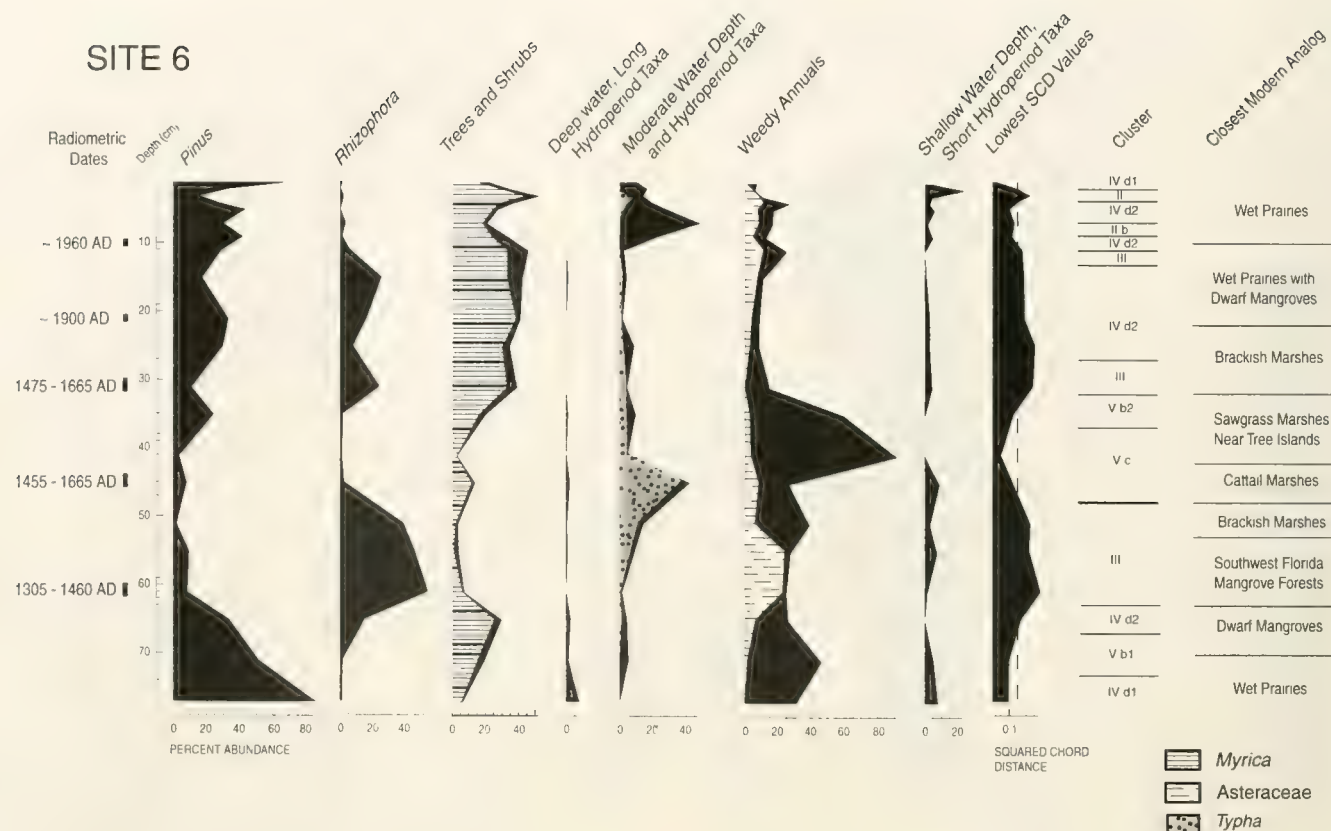
Vegetation at the southernmost site (site 8) changed little throughout the 20th century, because present salinity levels and vegetational composition apparently were established by late in the 18th century. Site 7, collected farther north in dwarf mangrove scrub, changed from fresh-water marshes to mangrove assemblages in the early to mid-20th century. This change probably reflects the combined effects of natural sea-level rise and reduced fresh-water flow from the Everglades. Additional evidence for hydrologic changes along Taylor Creek is provided by examination of aerial photographs taken between 1940 and 1994. These photographs show infilling of a lake along Taylor Creek, reducing its area by about half and infilling parts of the coastal zone west of the Taylor Creek mouth (Schaffranek *et al.*, 2001).

In Taylor Slough, vegetation at both sites 5 and 6 changed after 1930. At site 5, pollen of asters and sedges increased greatly, which is suggestive of greater disturbance, fluctuating water levels, and/or drier conditions. At site 6, mangrove abundance decreased by

1960, and marsh pollen (*Cladium*, other Cyperaceae, Poaceae, and *Typha*) increased to abundances unprecedented in the past 2,000 years. This shift to sawgrass marshes may reflect the influence of construction of the C-111 canal and South Dade Conveyance System in the early 1960s; management of these control structures ensures minimum monthly deliveries of water to Taylor Slough (Light and Dineen, 1994), possibly providing more annually constant hydrology, deeper water, and longer hydroperiods than occurred naturally at this site.

DISCUSSION

Over most of the last two millennia, water depths in much of the Everglades appear to have been deeper than today with longer hydroperiods. In the Ridge and Slough, the presence of slough vegetation between 0 A.D. and 800 A.D. and between 1200 A.D. and 1600 A.D. indicates the long-term existence of deep water and long hydroperiods. In Taylor Slough and sites near Florida Bay, the presence of wet prairie and sparse sawgrass marsh vegetation prior to 1200 A.D. indi-



Text-figure 7.—Percent abundance of pollen of major plant groups at site 6, southern Taylor Slough. SCD values show lowest squared chord distance values for modern analogs; SCD < 0.15 are considered to be close analogs for fossil assemblages. Cluster designations refer to clusters designated in Text-figure 3 and Table 3.

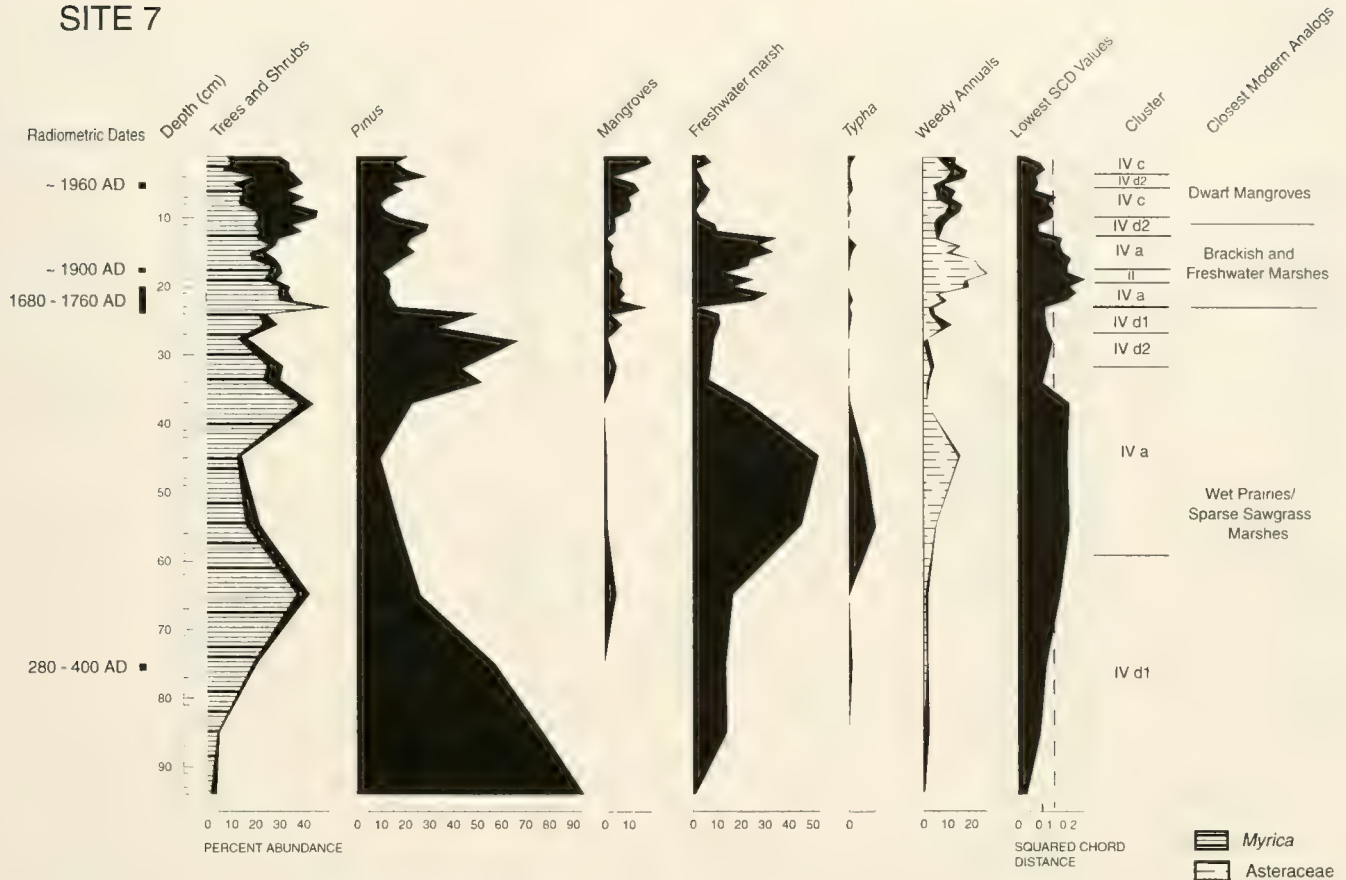
icates fresh-water conditions and short to moderate hydroperiods. These long-term differences in hydrologic regimes between northern and southern sites is reflected in the present vegetational distribution and substrate type and probably reflects underlying geologic controls, including differences in the underlying limestone. Northern sites are underlain by the Fort Thompson Formation, which consists of a series of alternating freshwater and marine limestones. Southern sites are underlain by the Miami Limestone, consisting of an upper, oolitic limestone overlying a bryozoan facies (Gleason and Stone, 1994).

The impact of climate variability on Everglades vegetation and hydrology is indicated in sediments deposited between the 9th to 13th centuries. During this time, water was shallower at most Ridge and Slough sites, with the greater abundance of weedy annuals suggesting rapid drying or prolonged droughts. Near Florida Bay, salinity increased at this time. Also during this interval, known as the Medieval Warm Period (MWP) (9th to 14th centuries) (Hughes and Diaz, 1994), prolonged droughts have been documented in Haiti, Mexico, and North Carolina, as have lower lake levels in Mexico, and increased fire frequency in Costa Rica

(Hodell *et al.*, 1995; Horn and Sanford, 1992; Metcalfe and Hales, 1990; Stahle *et al.*, 1988). Although slow sedimentation rates at Everglades sites preclude detailed temporal analysis of vegetational patterns throughout this interval, the evidence for drier conditions is consistent with a broader regional pattern of warmer, drier conditions during the MWP.

Our data also indicate slightly drier terrestrial conditions in the 16th through 19th centuries. Although sedimentation rates in these cores do not allow detailed analysis of this interval, the broad patterns shown during the interval known as the Little Ice Age (LIA) (1550–1850 A.D.) (Bradley and Jones, 1993) are consistent with records of $\delta^{18}\text{O}$ from coral skeletons in Biscayne Bay indicating drier conditions in the 18th and 19th centuries (Swart *et al.*, 1996). Sea-surface temperatures 1°C cooler than today also are indicated by $\delta^{18}\text{O}$ data from corals and foraminifers in the Florida Straits and Sargasso Sea for the late part of the LIA (Druffel, 1982; Keigwin, 1996). Cooling of Gulf surface temperatures in climate models is correlated with lower precipitation levels (Overpeck *et al.*, 1989), which is consistent with drying trends shown by LIA pollen records from the Everglades.

SITE 7



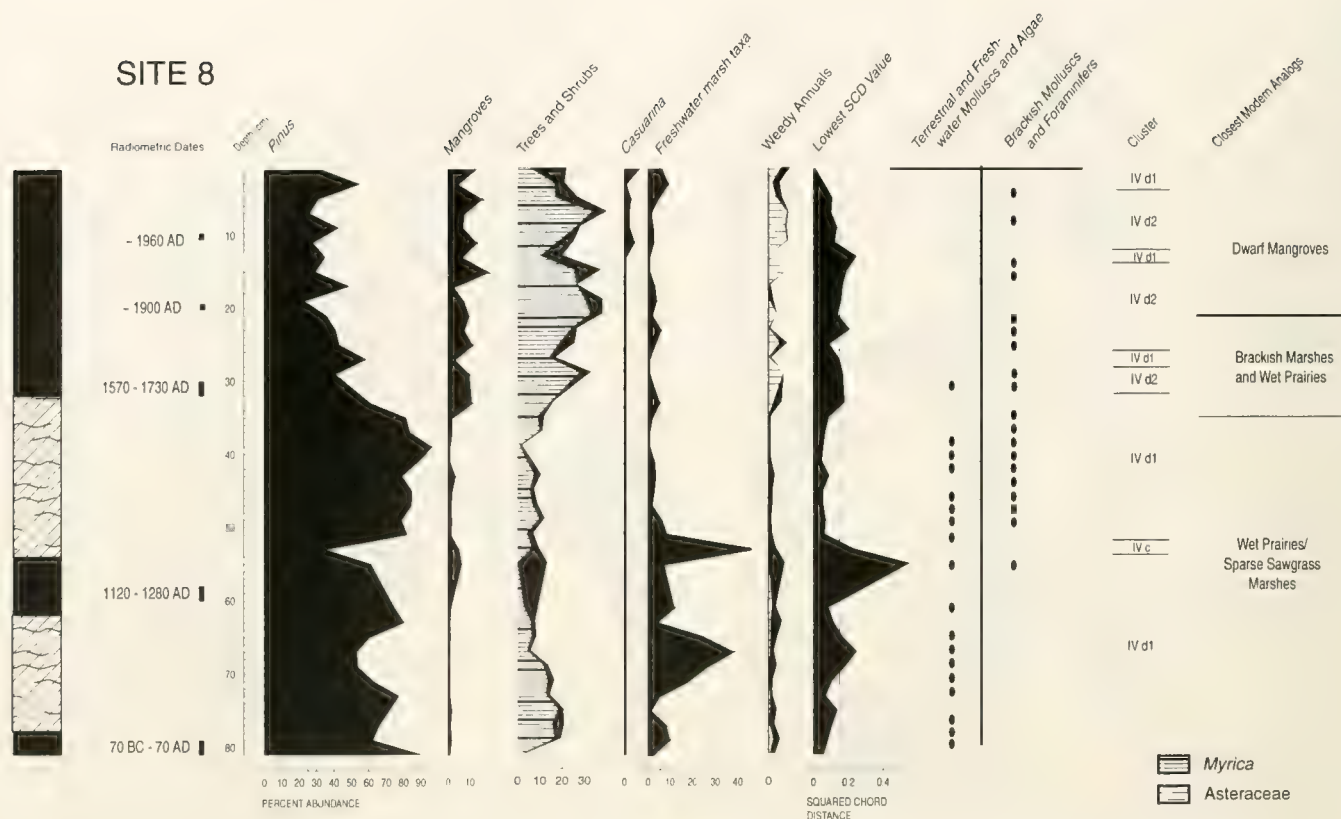
Text-figure 8.—Percent abundance of pollen of major plant groups at site 7, Taylor Creek. SCD values show lowest squared chord distance values for modern analogs; SCD <0.15 are considered to be close analogs for fossil assemblages. Cluster designations refer to clusters designated in Text-figure 3 and Table 3.

The advent and evolution of water-control practices in south Florida has resulted in unprecedented changes in vegetational distribution. The greatest and most regional impacts were seen by 1930, when shallower water and shorter hydroperiods are documented in most Everglades cores. These drier conditions occurred at a time of higher than average precipitation, indicating that vegetational and hydrologic changes resulted from hydrologic changes to the system. The combined effects of reduced sheet flow due to water diversion through canals and disrupted seasonal water supply due to construction of the Hoover Dike were sufficient to shift the Ridge and Slough ecosystem from a deep-water slough to a sawgrass marsh with abundant weedy annuals. At both sites in Taylor Slough, weedy species also increased in abundance, although the impact on water depths is less clear. In contrast, alterations associated with construction of the Central & South Florida (C & SF) Project in the 1950s and 1960s appear to have had more localized impacts on marsh vegetation. Some sites underwent striking changes after 1960, such as expansion of cattail marsh-

es at nutrient-enriched sites, whereas other sites saw minimal change.

These observations are particularly relevant in light of suggestions that restoration goals for the Everglades be aimed at rainfall and runoff conditions that existed before the C&SF Project was completed in the early 1960s (Light and Dineen, 1994). Our data clearly indicate that the major alterations of the system occurred in the early 20th century, when construction of muck canals linking Lake Okeechobee to the Atlantic Ocean, the Hoover Dike along the southern shore of Lake Okeechobee. Thus, the early- to mid-20th century should not be construed as the "natural" state of the Everglades ecosystem. Rather, reconstructions of the early 19th-century Everglades provide a more realistic estimate of the "natural" state that our data indicate had persisted for the previous two to three centuries.

These data also provide a model for how an undisturbed wetland ecosystem responds to changing climatic conditions; data indicating drier conditions during the Medieval Warm Period are consistent with the predicted response of the Everglades wetland to pos-



Text-figure 9.—Percent abundance of pollen of major plant groups at site 8, Mud Creek. SCD values show lowest squared chord distance values for modern analogs; SCD <0.15 are considered to be close analogs for fossil assemblages. Cluster designations refer to clusters designated in Text-figure 3 and Table 3. Ovals indicate presence of molluscs or foraminifers picked from sediments. Foraminifer presence also was noted when foraminifer linings ("microforams") were observed in palynological preparations. Fresh-water algal presence is based on presence of *Ovoidites* in palynological preparations.

sible global warming over the next century (Watson *et al.*, 1996). Additionally, the drier conditions indicated during parts of the Little Ice Age are consistent with climate model predictions of lower precipitation due to cooling of Gulf surface temperatures (Overpeck *et al.*, 1989). A more difficult question to address confidently is the impact of future warming on an already disturbed ecosystem. Prior to compartmentalization of the marshes by canals and levees in the 20th century, it appears that broad-scale subenvironments of the Ev-

erglades responded similarly to climatic fluctuations. Changes over the last century have altered water levels and the natural rhythm of seasonal hydroperiod fluctuations in the Everglades wetland, resulting in a landscape characterized by localized fluctuations in hydroperiod, disturbance, nutrient status, and salinity. The resulting ecological heterogeneity makes modeling predictions of system-wide changes due either to future climatic change or alterations in water-control practices much more problematic.

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CHAPTER 5

HYDROLOGY, VEGETATION, AND CLIMATE CHANGE IN THE SOUTHERN EVERGLADES DURING THE HOLOCENE

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ABSTRACT

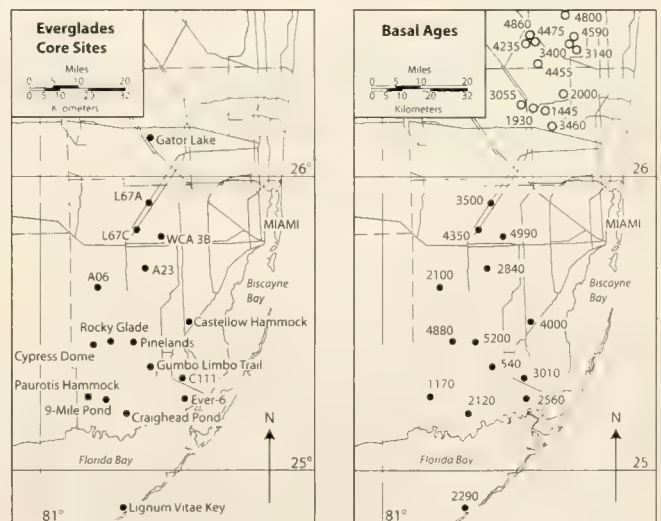
Paleoecological study of 18 AMS-dated sediment cores from the southern Everglades provides evidence of a shifting mosaic of biotic communities in the past similar to those on the Everglades landscape today. Our results also indicate initiation of Everglades peatlands at 5000 yr B.P., the importance of fire (from charcoal analysis) as a structuring agent in the tropical Everglades, evidence of past plant communities (*Isoetes* marshes) not present in the modern landscape, and the introduction of exotic plants (*Schinus*, *Casuarina*, etc.) today. Past vegetation changes are documented by pollen and sclereid changes. Past water level changes are documented by plant community changes, diatom species and habitat changes, sponge spicule changes, and by intervals of peat (wet) or marl (dry) deposition in the sediment cores. Marl deposition dominates today at these sites in the southern Everglades, a long-term trend exacerbated by human impacts. The Everglades may become less complex in the near future as introduced plants outcompete native vegetation and decreased water levels result in decreased peat production. A rewetting plan must include both wet and dry seasonal cycles in order to preserve the shifting mosaic nature of the landscape and to maintain the Everglades as a functional habitat for both plants and animals.

INTRODUCTION

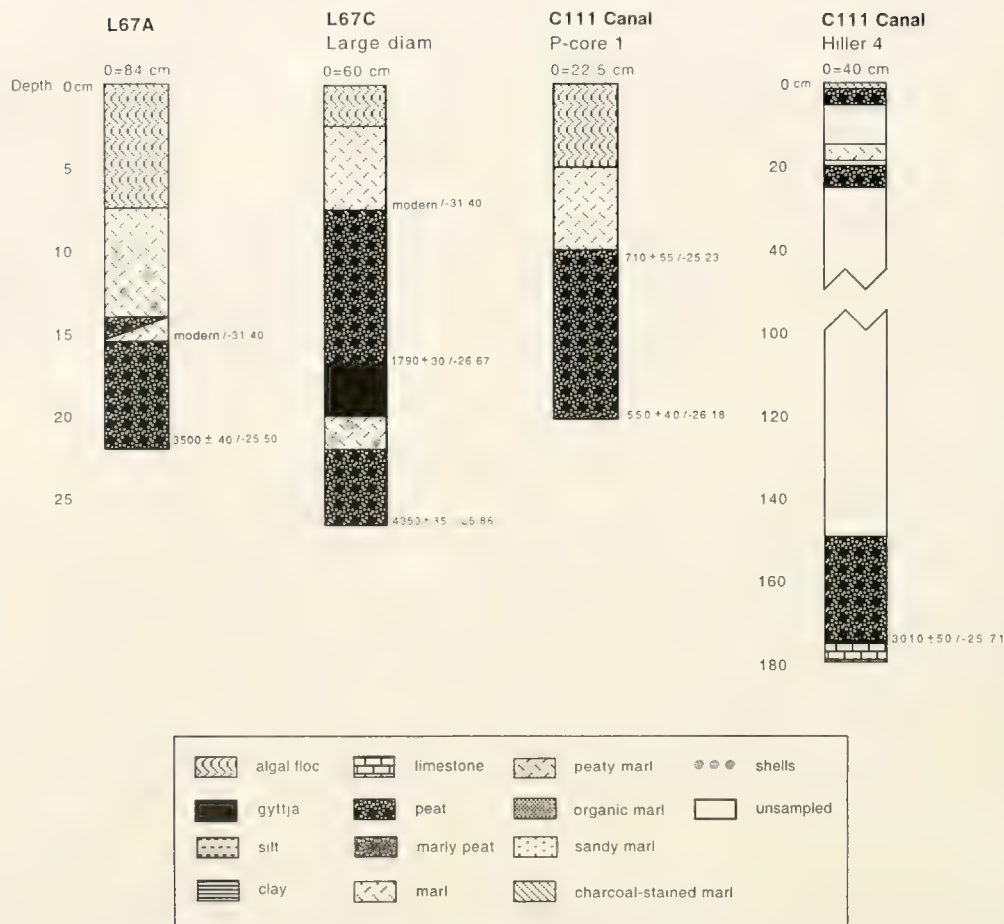
The Everglades is an unique subtropical and tropical hydroecologic region found at the southern end of the Florida peninsula below latitude 28°N. Sheetflow from the Kissimmee-Okeechobee drainage maintains the diverse biotic communities in the Everglades as it flows through marshes, hammocks, sloughs, and swamps to the ocean. Human activities in the past 100 years have decreased flow of water critical to the health of the natural Everglades. As South Florida population increases in coming years, pressure to divert more water and drain more land for development will increase. Recently Congress increased federal and local funding for a large-scale Everglades restoration effort. Conflicting demands from developers, landowners, and preservationists make restoration decisions by federal and state agencies charged with water and environment management extremely difficult.

To make informed choices managers need to understand the evolution of the Everglades landscape. Only paleoecologic analyses can provide an understanding of the processes which made the Everglades. Previous paleoecologic studies of the region (Riegel, 1965; Nichols, 1974; Gleason and Spackman, 1974; Gleason and Stone, 1994) were concentrated in the coastal southwestern or northern (the Water Conservation Areas, WCA) sections of the historical Everglades. We

undertook paleoecological analysis of 38 sediment cores (Text-fig. 1) from 17 sites in the southern section of the Everglades concentrating on Everglades National Park (ENP) and the southern parts of WCA3 to



Text-figure 1.—a and b. Map of coring sites for this study in the southern Everglades (a). Distribution of basal organic sediment radiocarbon ages for cores in the southern Everglades (b). Filled circles denote sites in this study and are all AMS dates. Open circles show basal ages from studies cited in text and are all conventional bulk radiocarbon dates. All ages are expressed in radiocarbon years before present (1950 A.D.) (yr B.P.).



Text-figure 2.—Sediment stratigraphies of cores obtained from Everglades sites. Radiocarbon dates and stable carbon isotope values ($\delta^{13}C$) are to the right of each sediment core. Water depth is represented by 0 = # at the top of each stratigraphic column.

provide a chronology for the development of the Everglades and to compare the past vegetation and hydrology with that of the modern landscape.

ACKNOWLEDGMENTS

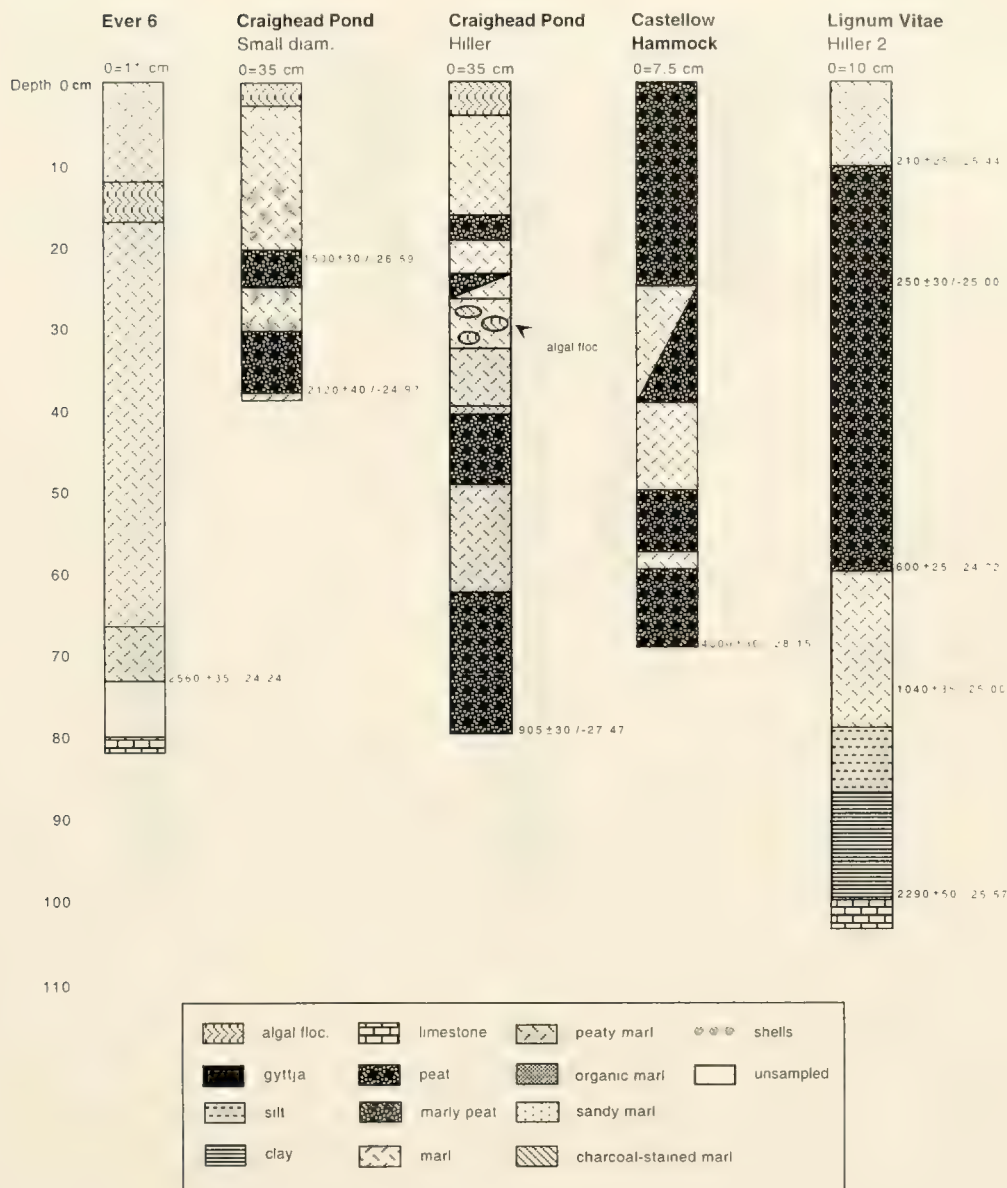
We thank the many people at both Everglades National Park South Florida Natural Resources Center and at the Center for Climatic Research (CCR) who helped facilitate this study. The field work was aided by D. McJunkin, R. S. Webb, P. Killoran, J. Stott, S. S. Winkler, W. Loftus, W. Robertson, R. Rehner, and M. Nesbitt. AMS-radiocarbon dates were run at the AMS-facilities at Woods Hole Oceanographic Institute and Lawrence Livermore Laboratory. I. Treichel, University of Wisconsin Chemistry Department ran the samples for mass spectrometry. The Fairchild Tropical Garden, Miami, Florida, allowed access to their herbarium. This study was funded by NPS grant agreement #CA 5280-2-9010 from Everglades National Park to M. G. Winkler and by NSF grants ATM-9101919 (COHMAP), ATM-9510668 (TEMPO),

ATM-9318973 (Interdisciplinary Research Program in Climatology) to J. E. Kutzbach at CCR, University of Wisconsin-Madison. The stable carbon isotope measurements were partially supported by NIH Grant GM18939 to W. W. Cleland, Dept. of Biochemistry, UW-Madison.

AMS Radiocarbon dates from the National Ocean Sciences Accelerator Mass Spectrometry (NOSAMS) facility at Woods Hole Oceanographic Institute were partially funded by NSF cooperative agreement OCE801015. This is CCR Contribution No. 757.

METHODS

Cores were taken with the Hiller corer, hand-driven polycarbonate tubes, freeze corer, or modified Livingston piston-corer as field conditions, transport considerations, and/or sediment type dictated. All sites were cored to bedrock except for Gator Lake, a deep sink-hole lake, although at some sites (Rocky Glades and C111) coring was discontinuous (Text-fig. 2). Sediments from all sites were analyzed by loss-of-weight-



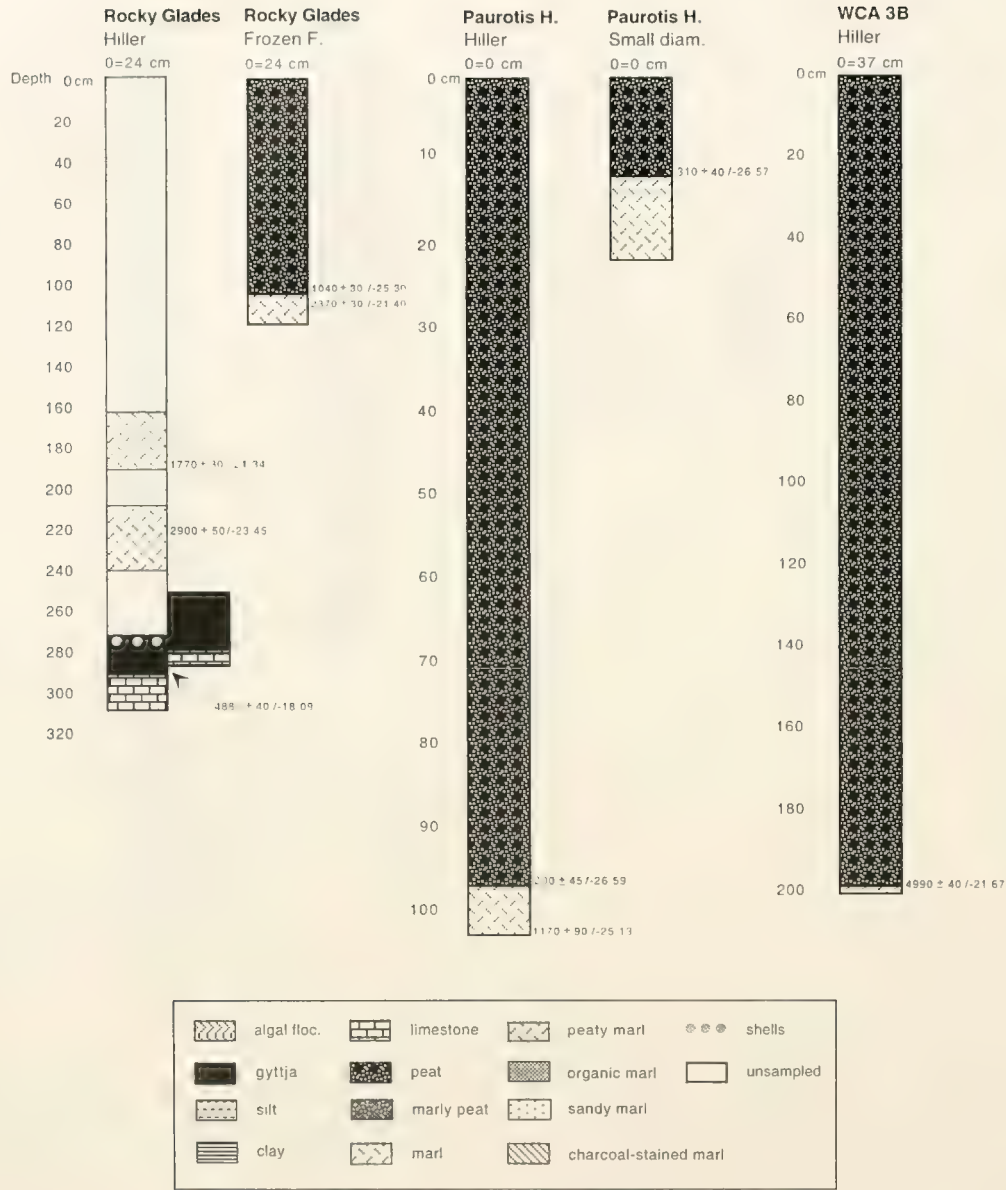
on-ignition (LOI) (Berglund and Ralska-Jasiewiczowa, 1986) and high temperature LOI (HLOI) (Dean, 1974) to determine sediment composition (marl or peat). Fifty samples of basal and other organic sediments from the cores were radiocarbon-dated by Accelerator Mass Spectrometry (AMS) techniques. Sediment chemistry was obtained by Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) analysis run at the University of Wisconsin–Madison Extension Soil and Plant Analysis Laboratory (Schulte *et al.*, 1987) to determine changes in the concentrations of atmospherically- and locally-deposited elements and nutrients. Selected cores were analyzed for charcoal following the method of Winkler (1985); diatoms and other algae

(Winkler, 1994a); pollen (Gray, 1965; Faegri and Iversen, 1975); and cladocera (Frey 1986). Sponge spicules and *Nymphaea* (white water lily) and *Cladium* (sawgrass) sclereids were counted during cladoceran and/or pollen counts (Winkler *et al.*, 1996a).

RESULTS AND DISCUSSION

STRATIGRAPHY AND DATING

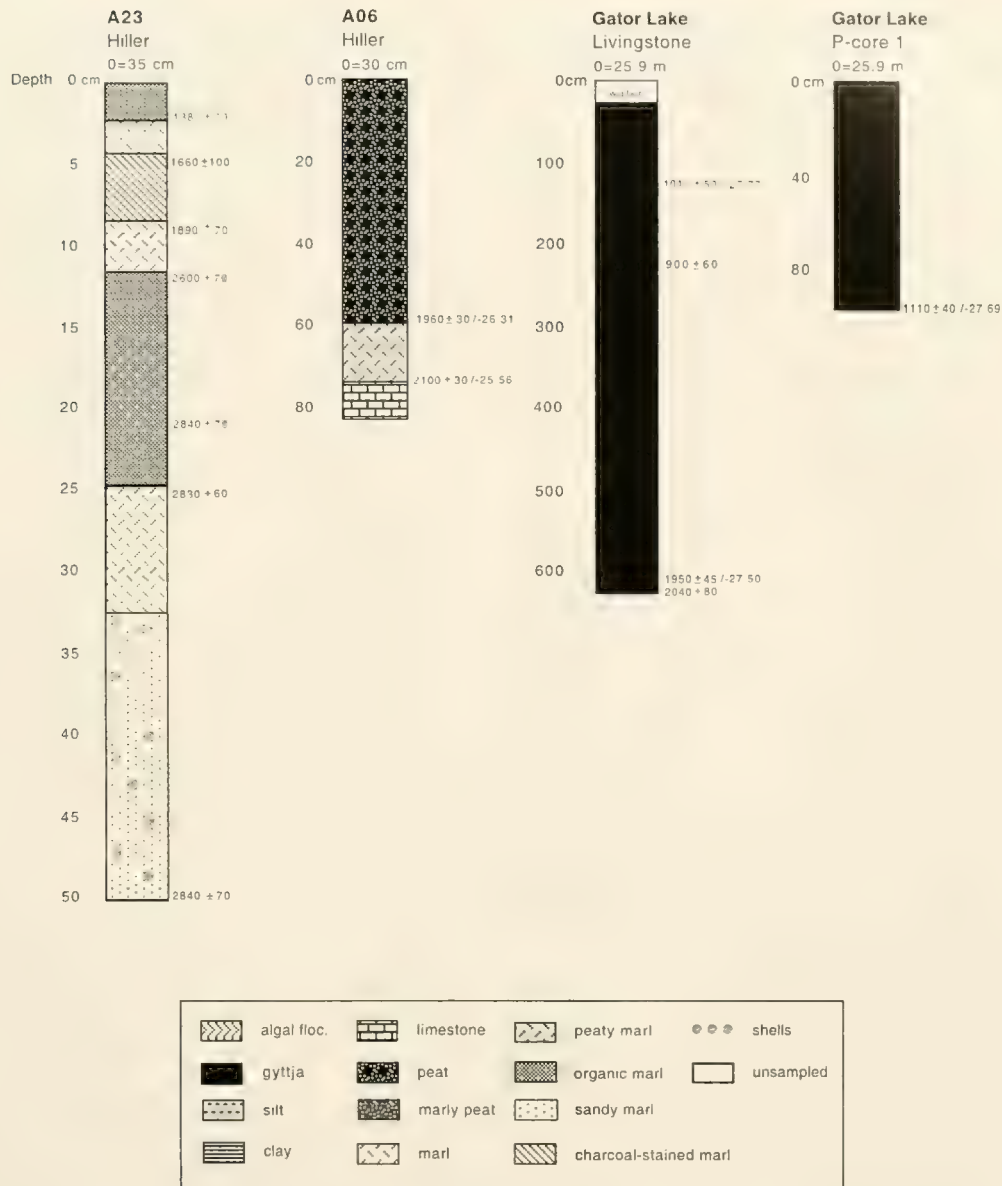
The unique landscape that is the Everglades in southern Florida is one that presents dating and interpretive difficulties for the paleoecologist. The landscape evolved from and is maintained by seasonal water-level extremes and frequent peat-consuming fires



Text-figure 2.— Continued.

(Robertson, 1953; Gunderson and Snyder, 1994). Charcoal is found at many levels in sediment cores (Cohen and Spackman, 1974; Duever *et al.*, 1985). Low water levels during drought, exacerbated by modern drainage and canalization, expose ancient peats which are then destroyed by oxidation and decomposition (Shih, 1980; Duever *et al.*, 1985; Snyder and Davidson, 1994). Dewatered peat is also loose and friable and can be scattered by winds or moved downstream when water levels increase. In addition, gases from the decomposition of peat during low water levels weaken tree islands and permit storm-force winds to cause tree islands and chunks of hammock peat to break off and be transported downstream where they

become the locus of further peat accumulation thus confounding interpretation of the Everglades environments. When there is marl in the sequence there is the possibility of hiatus in the record because transition to marl-forming conditions may involve sediment decomposition. In addition, when peat is subject to low water levels and/or fire there is also the possibility of hiatus in the record. Obtaining a continuous sedimentary record is not possible at many sites in the Everglades. In order to interpret this volatile region, many radiocarbon dates are required to determine the chronostratigraphic context at each site. Until a regional pattern is clear, intervals of interest in Everglades cores should be dated individually. Our goal was to date all



Text-figure 2.—Continued.

basal sediments and bracket-date as many of the obvious sediment transitions in our cores as funds allowed. Additional dates will be obtained as studies on these cores continue.

Text-figure 2 presents the sediment stratigraphy, radiocarbon dates, and stable carbon isotope values ($\delta^{13}\text{C}$) available for the sites. Sediment core depths ranged from 7 m of sediment at Gator Lake to 21 cm from a cypress dome. Alternations between peat and marl deposition are documented at several sites by sediment changes, LOI and carbonate analysis, and stable carbon isotope values. Peat deposition represents deep water-long hydroperiod, while marl deposition represents low water level-short hydroperiod. We hypothe-

size that temporal concurrence in hydrologic indicators suggests climatic forcing while local hydrological variability may be a result of topographical differences.

Rocky Glades, L67C, Castellow Hammock and WCA 3B have basal ages between 5000 and 4000 years Before Present (yr B. P.) (Table 1). These early dates occur at the base of peat overlying bedrock and correspond to basal ages obtained in earlier studies (Gleason and Spackman, 1974; Gleason and Stone, 1994). Cores taken at sites L67A, C111 Canal, and A23 show organic sediments or peat overlying limestone bedrock with basal ages ranging from 3500 to 2500 yr B. P. A23 radiocarbon dates indicate that the bottom 30 cm of sediment accumulated rapidly. Sites

Table 1.—Radiocarbon dates (accelerator mass spectrometric [AMS] and conventional) and stable carbon isotope values ($\delta^{13}\text{C}$) for this study. CAMS dates are from Center for Accelerator Mass Spectrometry, Lawrence Livermore National Laboratory. OS dates are from Woods Hole National Ocean Sciences AMS facility. WIS dates are from University of Wisconsin–Madison Radiocarbon Dating Laboratory. $\delta^{13}\text{C}$ values of -25‰ A are assumed rather than measured values.

Lab. ID	Site	Depth (cm)	Material	Date	$\delta^{13}\text{C}$
CAMS-7483	A23	2.0–3.0	org. marl	1380 ± 70	-25‰ A
CAMS-7484	A23	5.0–9.0	charcoal-stained marl	1660 ± 100	-25‰ A
CAMS-7485	A23	9.0–12.0	marl	1890 ± 70	-25‰ A
CAMS-7486	A23	12.0–21.0	org. marl	2600 ± 70	-25‰ A
CAMS-7487	A23	21.0–25.0	org. marl	2840 ± 80	-25‰ A
CAMS-7529	A23	25.0–33.0	marl	2830 ± 60	-25‰ A
CAMS-7499	A23	41.0–50.0	marl	2840 ± 70	-25‰ A
OS-3547	Rocky Glades, FF	101.6–106.7	peat	1040 ± 30	-25.3‰
OS-3554	Rocky Glades, FF	116.8–121.9	marl	2370 ± 30	-21.4‰
OS-3549	Rocky Glades, H2	195–200	org. carbon	1770 ± 30	-21.34‰
OS-3753	Rocky Glades, H2	195–200	inorg. carbon	5270 ± 45	-0.23‰
OS-3550	Rocky Glades, H3	232–242	wood	2900 ± 50	-23.45‰
OS-3548	Rocky Glades, H1	295–300	gyttja	4880 ± 40	-18.09‰
OS-3556	Lignumvitae	9.0–14.0	peat	210 ± 25	-25.44‰
OS-3557	Lignumvitae	20.0–25.0	peat	250 ± 30	-26.85‰
OS-3558	Lignumvitae	50.0–60.0	peat	600 ± 25	-24.72‰
OS-3559	Lignumvitae	75.0–79.5	org. carbon	1040 ± 35	-27.22‰
OS-3752	Lignumvitae	75.0–79.5	inorg. carbon	2610 ± 40	$+0.62\text{‰}$
OS-3560	Lignumvitae	96–100	peat	2290 ± 50	-25.57‰
OS-3551	Castellow Hammock	61.0–62.3	wood	4000 ± 30	-28.15‰
OS-3561	A06, H3	57.0–60.5	peat	1960 ± 30	-26.31‰
OS-3562	A06, H3	70.0–75.0	peat	2100 ± 30	-25.56‰
OS-8203	A06, H3	20.0–25.0	peat	modern	-26.53‰
OS-3731	L67A, F	13.5	peat	modern	-31.4‰
OS-3732	L67A, L	22.5	marl	3500 ± 40	-25.5‰
OS-2746	L67C, P-core 2	5.5–6.5	peaty marl	modern	-25‰ A
OS-3733	L67C, P-core 2	14.3–15.5	peat	1790 ± 30	-26.97‰
OS-3734	L67C, P-core 2	25.3–26.5	wood	4350 ± 35	-25.86‰
OS-3735	Paurotis Hammock, P-core 2	10.2–10.9	wood	310 ± 40	-26.57‰
OS-3736	Paurotis Hammock, Hiller	75.0–87.0	peat	200 ± 45	-26.59‰
OS-2742	Paurotis Hammock, Hiller	100–103	marl	1170 ± 90	-25.13‰
OS-3737	C111, P-core 1	10.6–11.7	peat	710 ± 55	-25.33‰
OS-3738	C111, P-core 1	17.6–18.6 (top)	peat	550 ± 40	-26.18‰
OS-2739	C111, Hiller 4H	169–174	peat	3010 ± 50	-25.71‰
OS-3744	Gator Lake	93.0–95.6	gyttja	1110 ± 40	-27.69‰
OS-3745	Gator Lake	190–191	gyttja	1010 ± 50	-27.77‰
OS-3746	Gator Lake	660–681	gyttja	1950 ± 45	-27.5‰
WIS-2338	Gator Lake	694–700	gyttja	2040 ± 80	-27.67‰
OS-2745	Craighead Pond, P-core	22.8–23.8	peat	1500 ± 30	-26.59‰
OS-2744	Craighead Pond, P-core	36.0–37.5	peat w/ clay	2120 ± 40	-24.92‰
OS-2743	Craighead Pond, Hiller 1	74.0–79.0	peat	905 ± 30	-27.47‰
OS-2741	Ever6, Hiller 1	68.0–73.0	marl w/ peat	2560 ± 35	-24.24‰
OS-2740	WCA 3B, Hiller	187–198	peat	4990 ± 40	-21.67‰

at A06, Craighead Pond, and Lignumvitae have basal ages between 2300 and 2100 yr B. P., although only Craighead Pond has peat at the base. Basal ages on the remaining cores fall between 1170 and 530 yr B. P. Paurotis Hammock core shows a transition from marl to peat at 310 yr B. P., possibly indicating the date of formation for this hammock. Sedimentation probably began at all of these sites in response to a rising water table. As noted below, our sequence of sediment cores would suggest at least four periods of long hydroperiod.

Marl deposition is observed at Rocky Glades and A23 between 2900 and 2800 yr B. P. and at Ever6 at 2560 yr B. P. Radiocarbon ages on basal portions of other marl deposits tend to cluster at about 1770 yr B. P., 1040 yr B. P., and between 210 yr B. P. and the present.

Data from these cores indicate that water levels rose high enough to allow sediment accumulation beginning about 5000 yr B. P. At all of these sites, except WCA 3B, basal sediments consisted of peat overlying bedrock. While WCA 3B has one of the earliest basal

dates on peat (4990 ± 40 yr B. P.), it overlies a marl deposit. The presence of marl under peat at WCA 3B suggests a chronological sequence similar to that of calcitic mud underlying peat in southern Lake Okeechobee (Brooks 1974; Gleason and Stone, 1994) and the Corkscrew Swamp (Kropp, 1976)—deposits which have all been radiocarbon dated at ca. 6500 yr B. P.

After the earliest peat deposition (5000–4000 yr B. P.) water levels continued to rise until c. 2900 yr B. P. when a number of sites show a transition to marl. The period from 2900–2300 yr B. P. is characterized by marl deposition. Gleason and Stone (1994) also report calcitic mud deposition at 2432 yr B. P. from Core 25 in south Water Conservation Area 3A west of Levee 67 and interpret hydroperiods to be short. However, an increase in water levels or hydroperiod may have occurred locally between 2600 and 2500 yr B. P. as indicated by organic sediments at Ever6 and A23. Deposition of organics here when widespread marl deposition occurred over the rest of the Everglades indicates the mosaic landscape form persisting even during times of short hydroperiod.

Craighead Pond, A06, and Lignumvitae show sediment beginning to accumulate over bedrock between 2290 and 2100 yr B. P. indicating a rise in water level or increase in hydroperiod. Gleason and Stone (1994) provide a radiocarbon age of 2036/2082 yr B. P. on peat in Core 25 and hypothesize wetter conditions during this period. A transition to peat deposition at A06 about 1960 yr B. P. and to marl mixed with organic material (charcoal-stained marl) at A23 at 1890 yr B. P., as well as a peat layer deposited prior to 1790 yr B. P. at L67C, suggest water levels remained high for several hundred years.

Marl deposition resumed at Rocky Glades at 1770 yr B. P. and at A23 at 1890 yr B. P. This drier period may have lasted until c. 1400 yr B. P. when organic deposition resumed at A23. Peat is also present prior to 1500 yr B. P. at Craighead Pond.

Conditions were probably dry or variable between 1400 and 1000 yr B. P. as some sites show marl and others peat. Again the mosaic of contemporaneous wetter and drier habitats is demonstrated in the sediment record. Between 1040 and 900 yr B. P. longer hydroperiods resumed and peat formation commenced at Craighead Pond and Rocky Glades. Hydroperiods remained long until about 550 yr B. P. as indicated by peat and organic sediment deposition at C111 and Lignumvitae.

Hydroperiods were again variable between 550 and 210 yr B. P. Paurotis Hammock and Lignumvitae reveal peat formation, while the C111 canal site exhibits a change to marl. The uppermost portions of the majority of cores have marl or algal deposits indicating

shortened hydroperiods. These sediments are dated as modern at L67C, L67A, and A06 or younger than 210 yr B. P. at Lignumvitae Key.

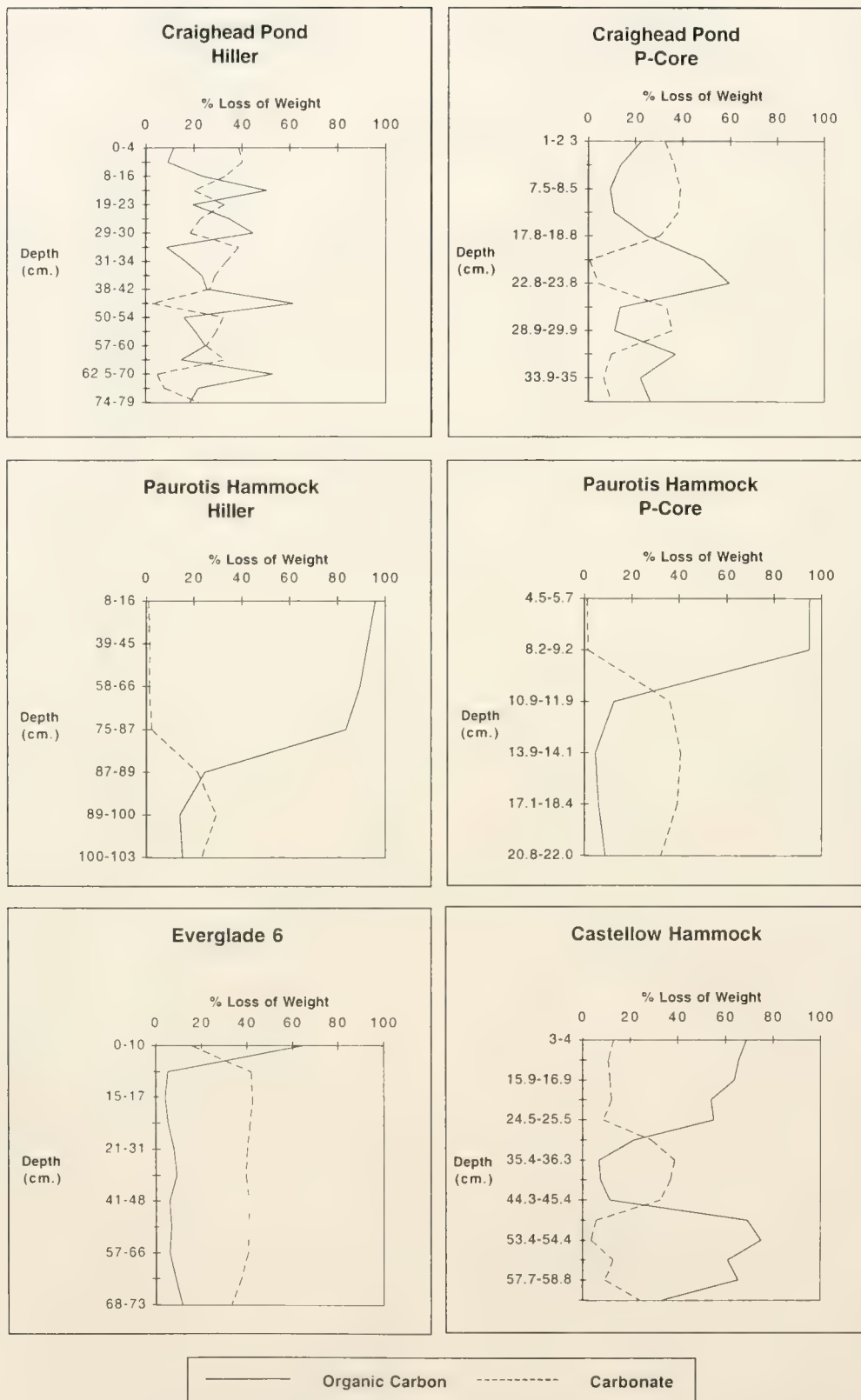
SEDIMENT CHEMISTRY

LOI and HLOI Analysis

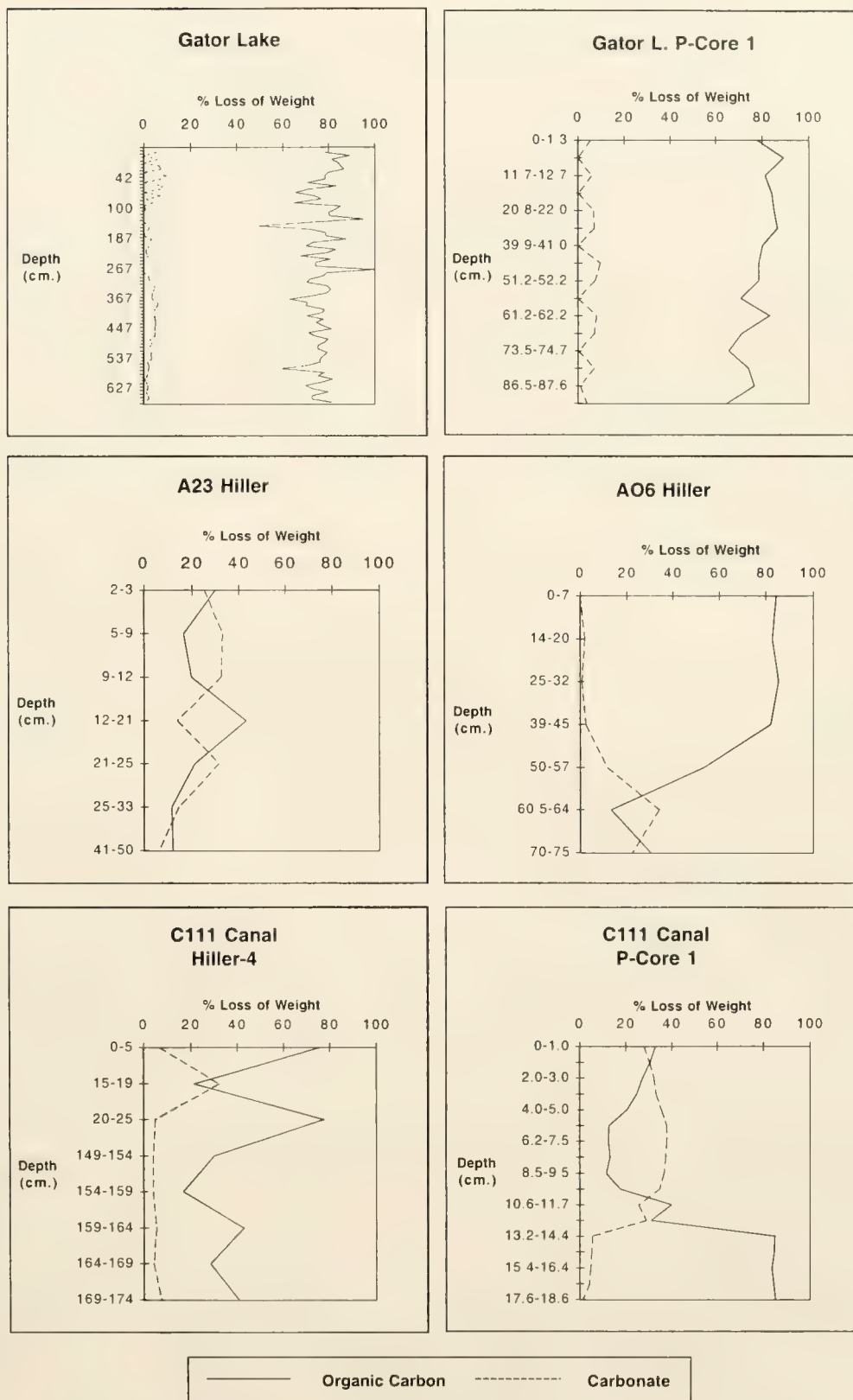
Text-figure 3 presents results from the LOI (% organic matter) and HLOI (% carbonate) analyses for selected sites. The values given in the graphs are the direct measurements due to the LOI and HLOI analytical procedures (Dean, 1974). The amount of organic matter in the Everglades sediments varies from a mean close to 85% in Gator Lake (a value that remains quite stable throughout the 7 meter sediment column) to less than 4% in Ever6. The percent carbonate also varies between 40% (at some time in the development of most sites) and less than 1% (at Gator Lake). At most sites the percent carbonate is greatest (approaching 40%) near the basal section of the cores, nearest to the limestone bedrock. $\delta^{13}\text{C}$ values of the carbonate (inorganic carbon) component of the sediment (see Table 1, Rocky Glades, 195–200 cm and Lignum Vitae 2, 75–79.5 cm) are -0.23 and $+0.62$, respectively, close to 0 (marine HCO_3^-), demonstrating the importance of the marine Miami and Key Largo limestones as the carbon source for much of the sediment deposition at these sites. Everglades peat, marly peat, and gyttja (lake sediments) are defined in our study terminology as sediments with more than 30% organic matter by LOI, while the Everglades marls in our cores contain a maximum of 30 to 40% carbonate by HLOI. Alternations between peat and marl are evident at 17 of the radiocarbon-dated cores including those from C-111, A06, A23, LV-2, Rocky Glades sinkhole site, L67C, Craighead Pond, and Paurotis Hammock. Ever6 and 9-Mile pond sites (Text-fig. 3) have elevated organic matter in the upper 15 cm, while WCA-3B (Text-fig. 3) has close to 90% organic matter throughout most of the core. Higher % HLOI values in the top meter of the Gator Lake core (Text-fig. 3), suggest increased atmospheric deposition of dust and minerals from 20th Century land-use changes in the region.

Charcoal Analysis

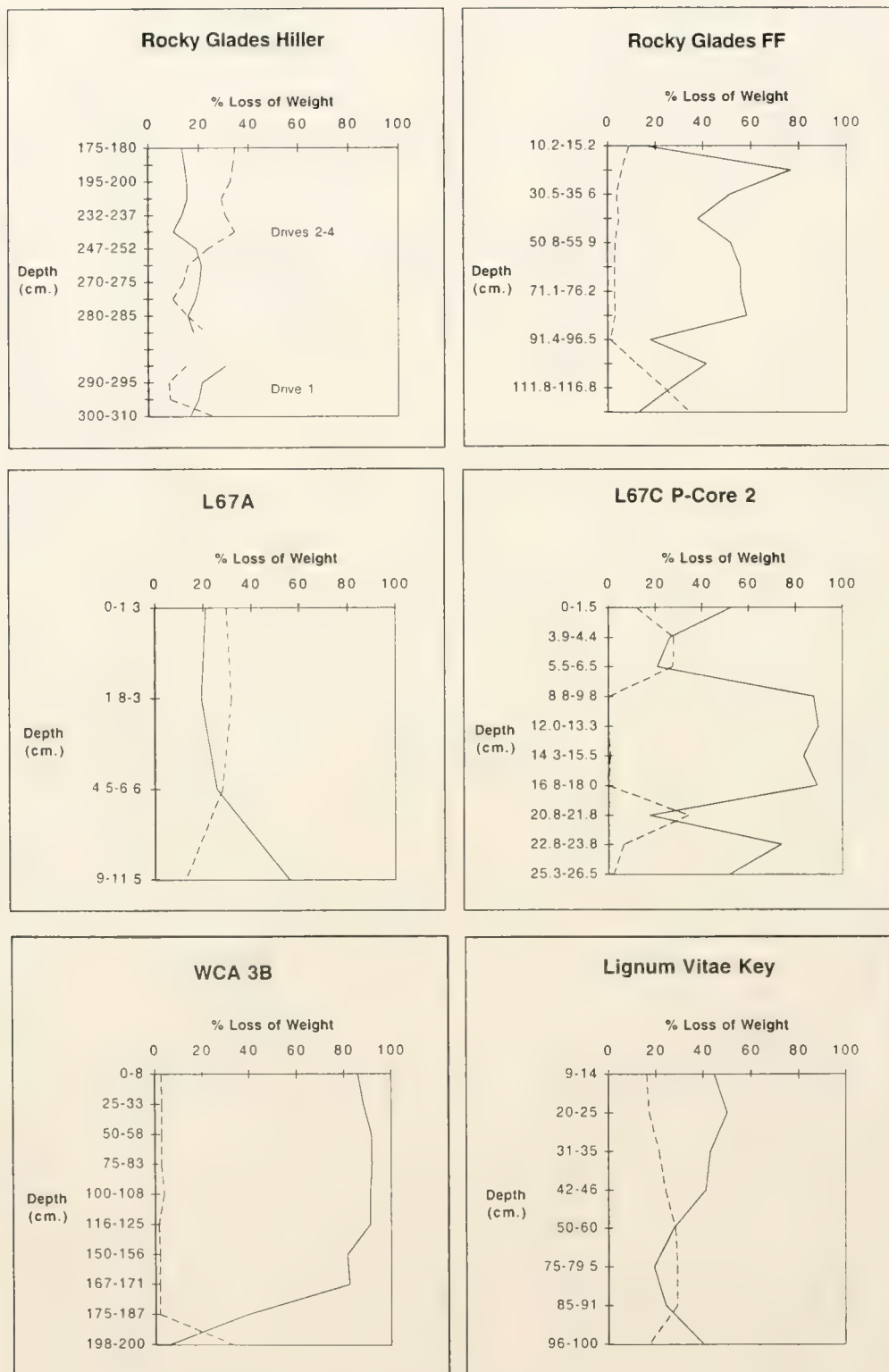
Fire burns off peat deposits locally and lowers the ground surface which allows ponds to form (Loveless, 1959a; Gunderson and Loftus, 1993) thus contributing to the mosaic nature of the landscape and causing hiatuses in the sediment record. A dramatic recent example of this destructive process occurred in spring of 1999 when wild and human-set accidental fires burned more than 20,000 ha of Everglades (Bragg, 1999). It may not be possible to find a complete paleohistorical



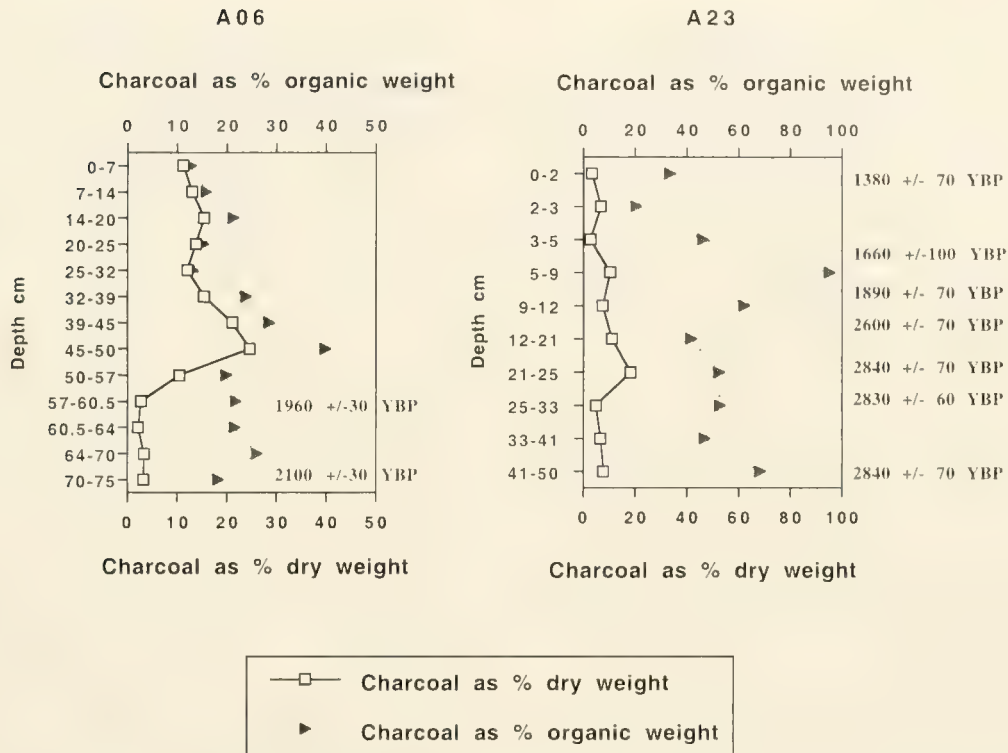
Text-figure 3.—Percent loss-on-ignition (LOI) and percent high temperature loss-on-ignition (HLOI) analyses for selected Everglades sediment cores. LOI is a measure of organic carbon and HLOI measures sediment carbonate.



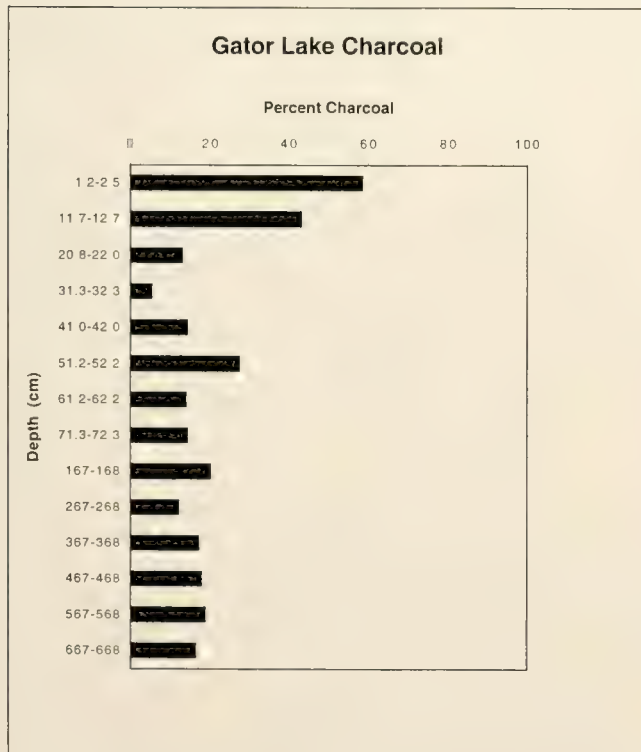
Text-figure 3.—Continued.



Text-figure 3.—Continued.



Text-figure 4.—Charcoal analyses of A06 and A23 presented as percent dry weight and as percent organic weight.



Text-figure 5.—Percent charcoal in Gator Lake sediments.

record in any single Everglades peat deposit. Much of the dark organic matter in some cores is charcoal (A23, Text-fig. 4) and even in peat sections which appear to be continuous, hiatuses occur. These findings dramatically underscore one of our conclusions: dating at close intervals is critical to understanding Everglades development.

Charcoal analysis of contiguous samples from cores at A06 and A23 (Text-fig. 4) showed that wildfires have been an agent of change on the Everglades landscape for at least the last few millennia. High charcoal abundances are noted after about 1600 yr B. P. at both sites when drier plant communities are evident from the pollen assemblages. In diatom slides abundant charcoal was noted throughout 70–45 cm at the A06 site and from 33–12 cm and again in the 9–5 cm sample interval at A23.

Charcoal analysis of the Gator Lake sediments shows higher charcoal abundances in the upper 20 cm (Text-fig. 5). This may indicate an increase in regional land-clearing fires and/or atmospheric deposition of particles of soot from industrial growth in the region since the 1940's. Fires used to burn off sugar cane growing areas in the Everglades Agricultural Area to the north of Gator Lake, may be one of the sources of increased charcoal in the recent sediments as well as a source of increased mercury (see Sediment Chem-

istry below). Fires due to drought, however, have been documented in WCA-3, the region surrounding Gator Lake, as recently as 1971 (Goodrick, 1984) and probably again in 1999 (Bragg, 1999). The charcoal evidence helps explain the presence of willow scrub surrounding Gator Lake as willow is known to colonize burned-over peat (Hofstetter, 1974; Olmstead and Loope, 1984). The pollen analysis of Gator Lake sediments (see below) suggests that willow was a recent addition to the vegetation near to Gator Lake.

Mineral and Heavy Metal Analysis

Total minerals and heavy metals in subsamples from Rocky Glades, C111, A06, A23, LV2, and Gator Lake were analyzed by ICP-OES (Table 2; Text-figs. 6 and 7). The results of these studies will be considered individually below. When contrasting prehistoric and recent concentrations of most elements (Table 2b) we found that lead, zinc, copper, and arsenic increase in the surface sediments (upper 1–2 cm) at most sites. Even at the *Lignumvitae* LV2 site where past and present saltwater intrusion has confounded element changes, surface sediments are highly enriched with lead. Most lead is deposited to these remote places through the atmosphere or, in the Everglades, through waterflow as roads and other concrete highway structures are washed by heavy summer rains and pollutants drain into surface waters. Lead in airboat fuels could also contribute to the metals pollution.

Mercury is elevated in both fish scales and sediments from recent levels of the Gator Lake core (Text-fig. 8). Mercury is used in the growing and processing of sugar cane in the Everglades Agricultural Area in the northern Everglades. Mercury has become a health problem for wildlife and humans in ENP (Loftus and Bass, 1992). The mineral and metals analyses show that even in the same drainage, sites such as A06 and A23 (Table 2), can have different allochthonous inputs.

Rocky Glades

Total mineral (Text-fig. 6a) and heavy metal (Text-fig. 6b) analyses of top 128 cm of sediments from Rocky Glades provides evidence of elevated heavy metal concentrations above 45 cm. Samples analyzed below 110 cm (dated at about 1000 yr B. P.) have lowest heavy metals concentrations. Additional dates are needed to identify the cultural horizon in this core. The total mineral analysis (Text-fig. 6a) indicates peak levels of all minerals except calcium at 95 cm depth in the core, almost directly overlying the 1000 B. P. date. High sodium at this point suggests that saltwater intrusion may have been the cause of elevated mineral concentrations. A similar, but smaller, peak occurs at

45 cm in the core, but is accompanied at this higher interval by elevated heavy metals. The surface sediment has high concentrations of copper, zinc, manganese, arsenic, lead, and selenium (Text-fig. 6b). Calcium (Text-fig. 6a) is elevated in the bottom marl sediments of the frozen core (Text-fig. 2) and in the top surface sediment where LOI and HLOI analyses (Text-fig. 3) document marl deposition (decreased organic carbon and increased carbonate).

C111-core 4H

ICP analyses of the top and bottom sediments of a 179 cm core from C111 (core 4H) (Text-figs. 7a and 7b) suggest that saltwater intrusion and agricultural runoff both affect the sedimentation in this region of the Everglades. A near basal date for C111 core 4H at 170 cm is about 3000 yr B. P. However, in these bottom sediments there are elevated metal and mineral levels which suggest that there may have been a saltwater intrusion, an hiatus in the peat and concentration of elements, or diagenesis and mixing at this site. Canal construction may have also affected the stratigraphy at this site although we moved away from the canal road and berm before coring. Calcium and manganese peak in the marl sediments at 15–19 cm. depth and lead has near peak values in the top sediments (Text-fig. 7b). Boron, phosphorus, and copper, minerals used in fertilizers (Hem, 1992) have high concentrations in the top sediments. Sodium is elevated in the top sediments also suggesting possible saltwater intrusion in this area.

Gator Lake

ICP total minerals were analyzed for two sediment samples, 3.6 and 681 cm, from Gator Lake (Table 2a). The 3.6 cm sample is from the modern sediments and the 680–681 cm sample has been AMS radiocarbon-dated at 1950 ± 45 yr B. P. Similar to the results from C111 core 4H, boron and copper are elevated in the surface sediments of Gator Lake. These values suggest enrichment from agricultural practices in the region.

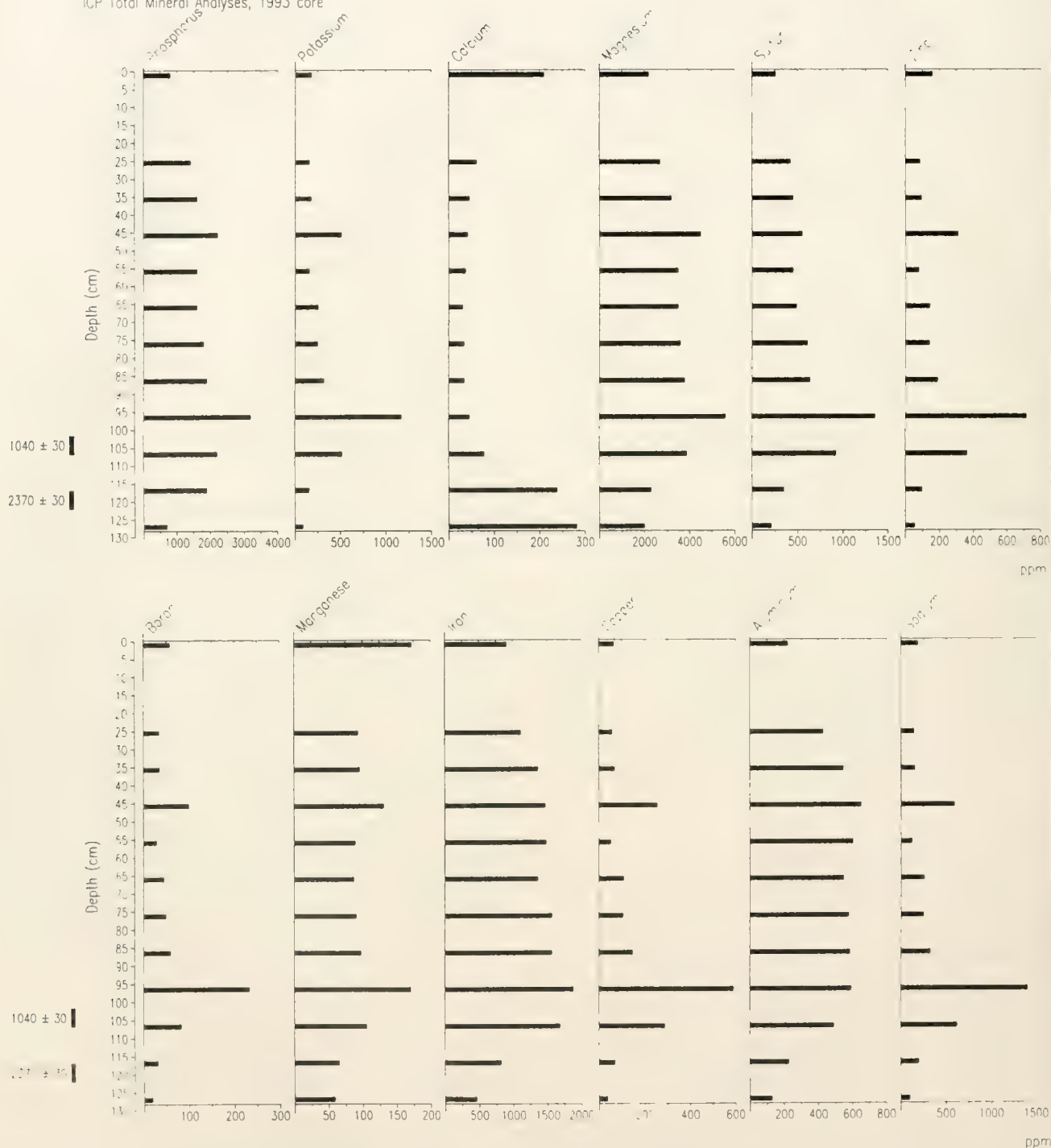
A06, A23, and LV2

Surface and core bottom sediments were analyzed at A06 and A23 sites for both total minerals and trace metals (Tables 2a and 2b). Percent N (% total nitrogen) was also analyzed for the top and bottom samples of the A06 and A23 cores (Table 2a). Only trace metals were analyzed for LV2 (Table 2b). As at some of the other Everglades sites, phosphorus, boron, and copper, as well as nitrogen, are elevated in modern sediments at A06 suggesting agricultural enrichment, while calcium and manganese are high in the modern marls of

Table 2.—a. ICP-OES Total Minerals Analysis for top and bottom samples from Gator Lake, A06, and A23. Concentrations are given in ppm (parts per million) dry wt. b. ICP-OES Trace Metals Analysis for top and bottom samples from A23, A06, LV2, and for Gator Lake samples from 3.6 cm to 681 cm. Concentrations are given in ppm dry wt.

Total Minerals—ICP Analysis															
Site	Drive	Depth (cm)	P	K	Ca	Mg	S	Zn	B	Mn	Fe	Cu	Al	Na	N
17 GatorL	p-core 1	3.6	858.5	188.6	14170	806.7	5930	30.6	31.12	19.07	4008	18.64	1870	141	—
18 GatorL	7, 80–81	681	1499	288.8	16913	633.5	4137	25.5	14.84	56.89	4654	8.63	3647	291.3	—
23 A06	H1, 0–7	7	506.2	169.2	20009	1396	6606	25.69	40	26.54	4841	38.01	1751	783.2	3.1
24 A06	H2, 20–25	50	360.1	148.1	36132	1321	3192	8.38	12.24	31.28	8321	7.65	5821	416.3	1.9
26 A23	p-core 1	1	104.9	102.2	193944	1950	1464	12.65	16.07	146.5	6996	4.39	2093	336.2	1
25 A23	H1, 12–21	21	165.7	186.3	105705	1534	1770	6.59	6.54	83.15	15248	4.94	6969	322.6	1.3
Trace Metals—ICP Analysis															
			Cd	Co	Cr	Cu	Fe	Li	Mn	Mo	Ni	Pb	Zn	As	Se
1 A23	p-core 2	2	2.66	3.21	4.05	3.29	7813	1.27	182.2	1.92	4.29	13.61	10.63	18.94	9.71
2 A23	H1, 12–21	21	2.6	1.51	15.22	4.02	16939	12.73	69.03	4.42	4.72	5.47	5.27	15.74	9.29
3 A06	H1, 0–7	7	0.94	1.69	1.56	39	4844	2.34	28.32	2.64	3.44	21.39	25.19	26.3	17.9
4 A06	H2, 20–25	50	1.39	1.16	10.33	5.94	7575	8.84	38.71	4.04	3.24	7.19	6.65	18.1	12.3
5 LV2	1, 0–9	9	1.8	2.72	14.06	17.73	2510	6.99	57.29	5.84	6.5	13.98	32.16	13.97	9.82
6 LV2	4, 16–21	96	3.29	3.6	17.89	36.71	2485	5.86	48.87	6.36	6.92	8.35	51.7	20.78	15.94
7 GatorL	p-core 1	3.6	0.9	1.61	1.498	16.8	4063	2.24	19.91	3.43	3.29	9.98	29.04	25.1	17.1
8 GatorL	p-core 1	27.1	0.83	1.498	4.45	4.61	5674	2.28	52.89	3.42	3.05	9.25	27.41	23.3	15.8
9 GatorL	p-core 1	53.1	0.98	1.75	5.72	6.77	7506	2.72	71.97	6.83	3.57	10.8	78.8	27.3	18.5
10 GatorL	p-core 1	76.8	0.82	3	9.87	7.91	7579	2.75	70.08	5.75	4.22	8.98	56.05	22.7	15.4
11 GatorL	2, 80–81	180	1.33	2.38	6.75	11.37	7904	3.84	50.5	4.77	4.86	14.7	34.36	37.2	25.2
12 GatorL	3, 85–90	290	0.82	1.47	3.06	9.12	7799	2.23	137.4	4.1	3.01	9.09	50.3	23	15.6
13 GatorL	4, 90–91	385	1.45	2.6	2.41	6.09	6212	3.62	37.76	7.44	5.32	16.1	44.7	40.7	27.6
14 GatorL	5, 80–81	495	0.82	1.46	3.77	7.7	5295	3.4	72.56	3.17	2.99	9.05	43.67	22.9	15.5
16 GatorL	6, 80–81	595	0.82	1.46	7.52	10.86	6982	3.99	80.3	4.53	2.99	9.05	47.63	22.9	15.5
15 GatorL	7, 80–81	681	0.86	1.54	5.38	5.26	5861	2.89	75.04	4.95	3.15	9.55	24	24.2	16.4

Rocky Glades, Everglades National Park
ICP Total Mineral Analyses, 1993 core



Text-figure 6.—a and b. ICP-OES Total Mineral Analyses of the top 130 cm of Rocky Glades FF core (a). ICP-OES Heavy Metal Analyses of the top 130 cm of Rocky Glades (ENP) sediments from same core (b). Minerals and metals concentrations are given in ppm.

A23 p-core 1. Lead, zinc, and arsenic are elevated in the surface sediments of A23 p-core 2 (Table 2b), while copper, lead, zinc, arsenic, and selenium are high in the surface sediments of A06. LV2 has elevated

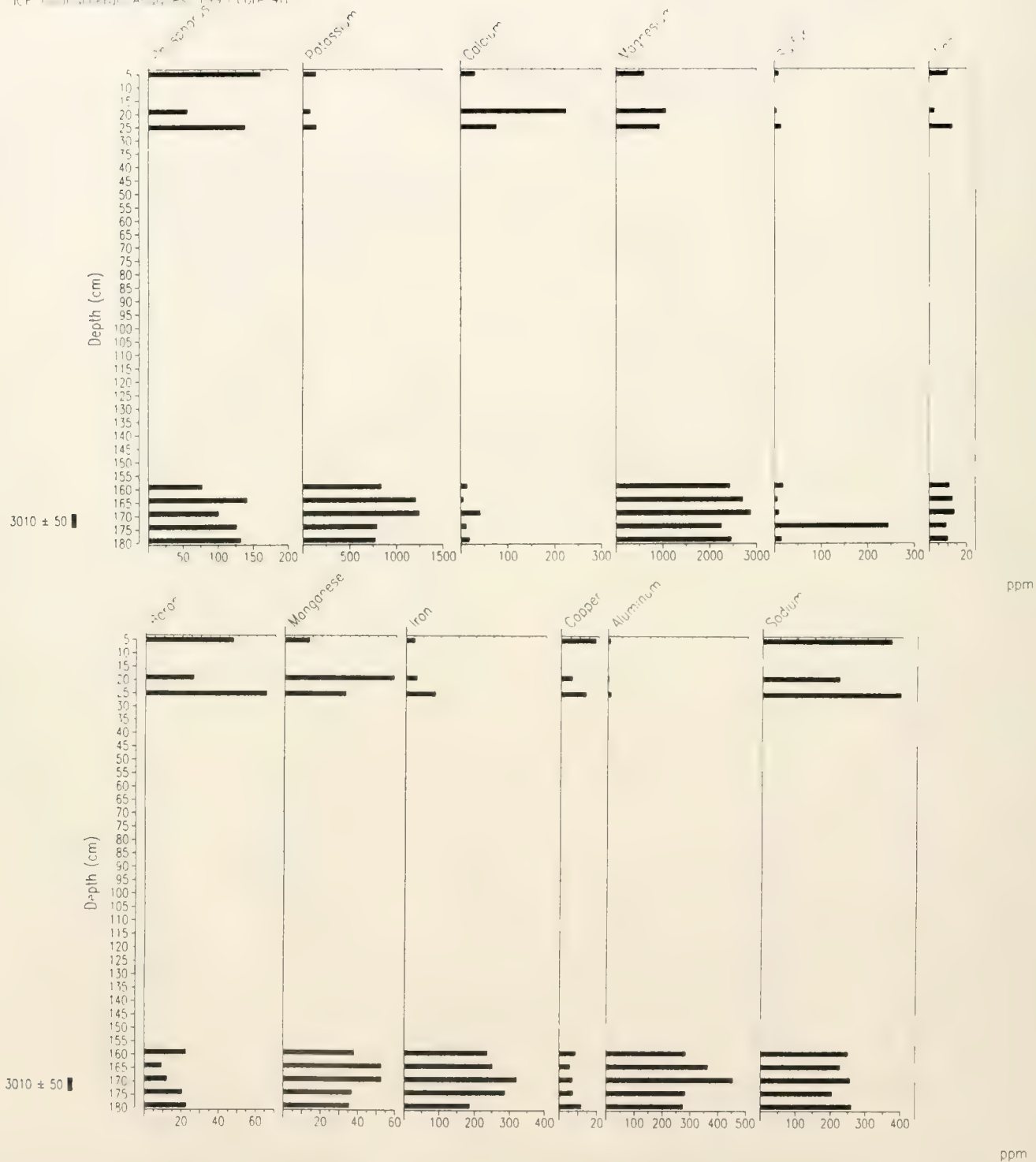
lead, lithium, and manganese in the surface sediments. Abundant marine diatoms in the LV2 surface sediments indicate frequent saltwater inundation of this mangrove-fringed coastal pond.

ROCKY GLADES, Everglades National Park
ICP Heavy Metal Analyses 1993 core



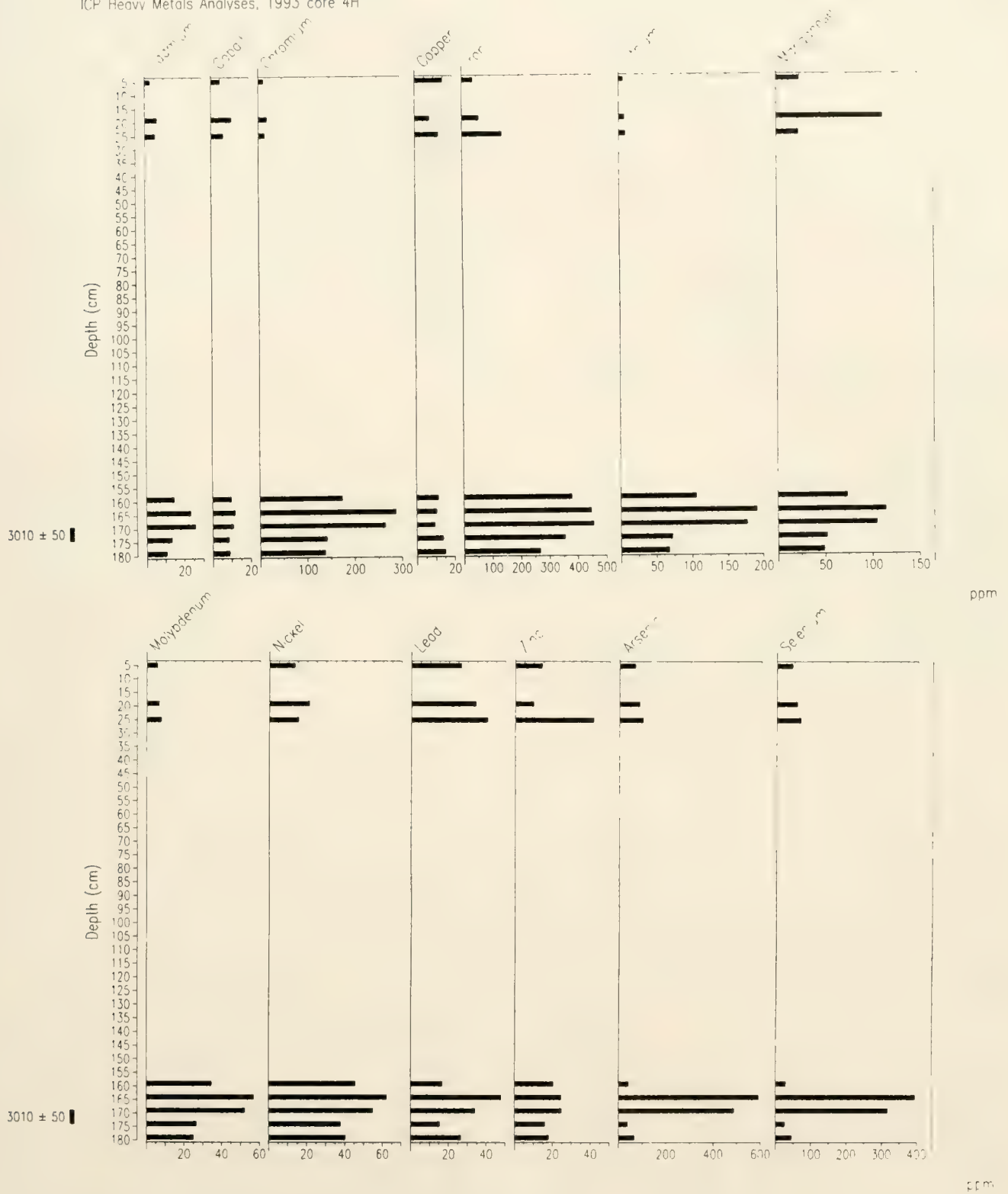
Text-figure 6.—Continued.

C111, Enbridge Natural Park
ICP Total Mineral Analysis, 1993 core 4H

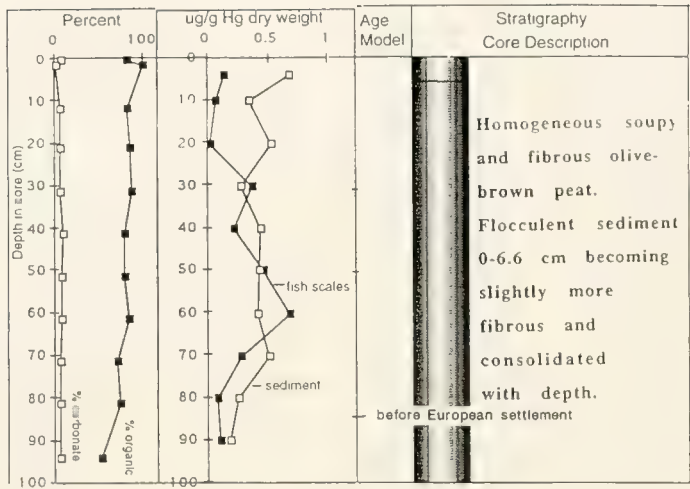


Text figure 7.—a and b. ICP-OES Total Mineral (a) and Heavy Metal Analyses (b) of the top 25 cm and the bottom 25 cm (155–180 cm) from sediment cores from C-111, ENP. Minerals and metals concentrations are given in ppm.

C111 Everglades National Park
ICP Heavy Metals Analyses, 1993 core 4H



Text-figure 7.—Continued.



Text-figure 8.—Mercury concentrations in Gator Lake sediments (p-core 1) and in fish scales found at the same depth in the sediments (modified from Jensen, 1994).

Sediment Stable Carbon Isotope Analysis

Charcoal isolated from the sediments of the A23H core was used for stable carbon isotope analyses (Table 3). The charcoal is considered to represent air- or water-borne upland carbon at most sites (Winkler, 1994b), but in the Everglades, charcoal may also come from the direct burning of peat at the site during drought. Stable carbon isotope values ($\delta^{13}\text{C}$) higher than -23 signal a proportional contribution of carbon from C-4 plants (such as *Muhlenbergia* and other drought-tolerant plants) in the region. The highest values in the A23H sequence ($\delta^{13}\text{C} -21.04$) are found from 9–12 cm when marl was being deposited at the site (Text-fig. 2). This result suggests an expansion of arid C-4 vegetation in the region, perhaps *Muhlenbergia* grass prairies, before about 1890 ± 70 yr B. P. and indicates that this vegetation association (which contains comparatively little biomass) burned frequently and contributed windborne charcoal to the sediment at A23H.

Other $\delta^{13}\text{C}$ results accompany the radiocarbon-dated samples. These values (Table 1; Text-fig. 2) are from analysis of whole sediment organic carbon which includes carbon from both upland and wetland sources.

Table 3.— $\delta^{13}\text{C}$ —Stable carbon isotope values for six A23H sediment samples. Analysis was performed on charcoal fraction isolated from the sediments at each depth.

Depth (cm)	$\delta^{13}\text{C}$
5–9	–23.48
9–12	–21.04
12–21	–24.01
21–25	–25.22
25–33	–25.51
41–50	–23.00

Highest values on organic carbon (values above $\delta^{13}\text{C} -21$) are found at the bottom of the WCA 3B core (4990 yr B. P.) influenced by the underlying marls, or in the Rocky Glades sediments before 4800 yr B. P. and from about 2500 to 1900 yr B. P., times when other sediment analyses also indicate drought.

In the two cases where separate samples of inorganic carbon and organic carbon were analyzed (Rocky Glades 195–200 cm and Lignumvitae LV-2, Dr. 4, 75–79.5 cm), the $\delta^{13}\text{C}$ values of inorganic carbon document dissolution of underlying marine coral ($\delta^{13}\text{C} -0.23$ and $+0.62$, respectively, close to marine limestone $\delta^{13}\text{C}$ of 0.0), rather than modern atmospheric CO_2 ($\delta^{13}\text{C} -7.0$), as the carbon source for marl-forming organisms. This is an interesting result in light of recent increases in atmospheric CO_2 and the need to identify carbon sources and sinks in the global carbon cycle. Additional stable carbon isotope sequences would aid interpretation of vegetation community change data from pollen.

BIOLOGICAL INDICATORS

Diatom Analysis

Diatom associations integrate environmental factors such as water chemistry, water temperature, water depth, and aquatic macrophyte presence or absence by their speciation, distribution, and abundance. Accumulation of diatom frustules in lake or peat sediments represents the response of the biota at various time scales. Seasonal and microhabitat variations are smoothed at medium frequency sampling intervals. Diatoms respond relatively rapidly to environmental changes such as pH and salinity gradients, and to changes in nutrient availability, water levels, and tem-

perature (Hustedt, 1939; Patrick and Reimer, 1966; Bradbury, 1975; Patrick, 1977; Gasse, 1980; Digerfeldt *et al.*, 1980; Rasanen and Tolonen, 1983; Charles, 1985; Charles *et al.*, 1986; Smol *et al.*, 1986; Winkler, 1988; Whitmore, 1989; Sweets *et al.*, 1989; Fritz, 1990; Sweets *et al.*, 1990; Blinn, 1993; Dixit *et al.*, 1993). Therefore, diatoms can be used to reconstruct the environmental history of lakes and wetlands and to delineate the biotic response to modern trophic and chemical conditions caused by land use and other changes. Correlation of chemical variables, morphometric factors, disturbance indicators, and diatom percentages, enables separation of some of the factors affecting the diatom distribution within lakes (Winkler, 1988).

Diatoms were identified using floras compiled by Hustedt (1930, 1939, 1955), Huber-Pestalozzi (1942), Patrick and Reimer (1966, 1975), Pergallo and Pergallo (1965), Koppen (1975, 1978), Florin (1980), Foged (1980, 1984), Gasse (1980), Germain (1981), Hakansson and Locker (1981), Gasse *et al.*, (1983), Gasse and Tekaiia (1983); Haworth (1983), Bateman and Rushforth (1984), Camburn *et al.* (1984–1986), Hakansson and Stoermer (1984), Stoermer and Hakansson (1984), Krammer and Lange-Bertalot (1985, 1986, 1988, 1991a,b), Camburn and Kingston (1986), Hakansson (1986a,b), Dodd (1987), Klee and Schmidt (1987), Kling and Hakansson (1988), and Scherer (1988).

Diatoms have been analyzed at four sites, Gator Lake, A23H, A06, and LV2. Each site will be discussed individually below, while the Diatom Discussion section will include consideration of results from all of the sites.

Gator Lake

Diatom analysis of the Gator Lake sediments (Text-fig. 9) reveals two zones devoid of diatoms: before 1900 yr B. P. (before 650 cm) and after about 1600 yr B. P. (above 450 cm). The interval between 1900 and 1600 yr B. P. has abundant acid to circumneutral planktonic diatoms dominated by *Aulacoseira ambigua* and other *Aulacoseira* species, including a large number of diatoms which may be a new species of *Aulacoseira* (Plate 1, figs. 1 and 2). This zone of deeper water, as indicated by the planktonic diatoms, is concurrent with one described below at sites in the Northeast Shark River Slough and may indicate a change in the regional hydrology at that time. A diverse assemblage of littoral diatoms including *Eunotia*, *Navicula*, and *Neidium*, and other algae (*Pediastrum* and desmids) are also present during this wet time between 650 and 450 cm.

At Gator Lake, the intervals with sparse diatoms are

the only ones with abundant sponge spicules (Pl. 1,3 and 4), as well as abundant rhizopod amoeba tests, chrysophyte cysts, Nymphaceae sclereids (Pl. 1,6), fungal spores, and pyrite framboids. The few diatoms in the surface sediment sample suggest an increase in taxa such as *Aulacoseira granulata* and varieties, and *Rhizosolenia* resting spores. These species dwell in more alkaline and more nutrient-rich water than diatom species found in the lower levels of the core.

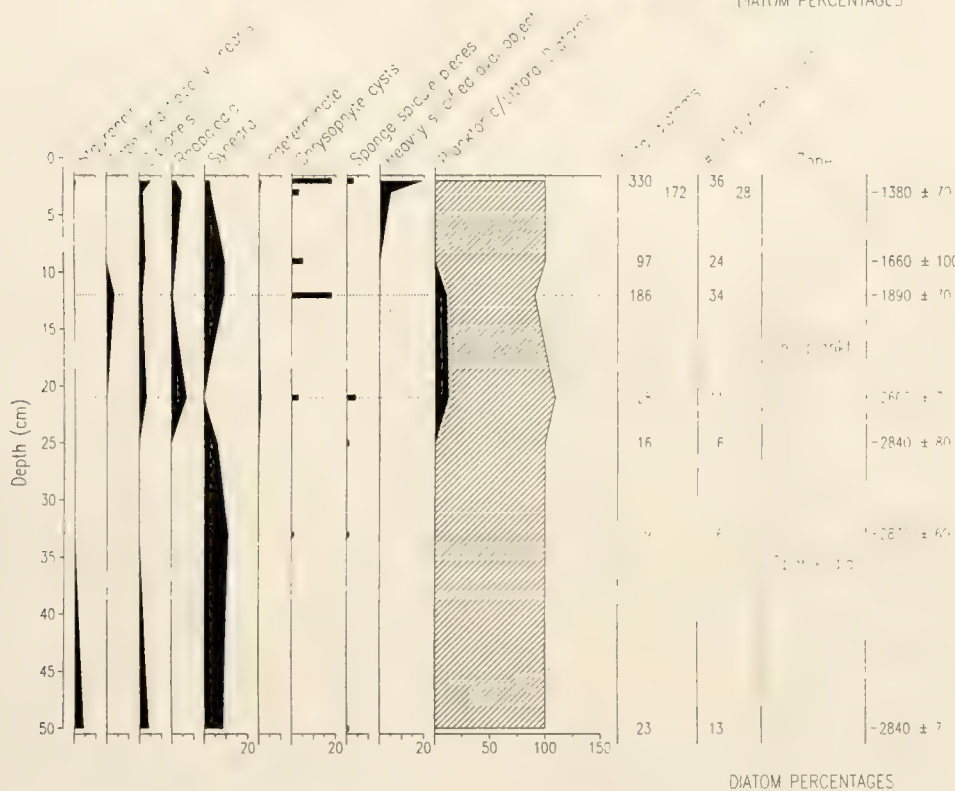
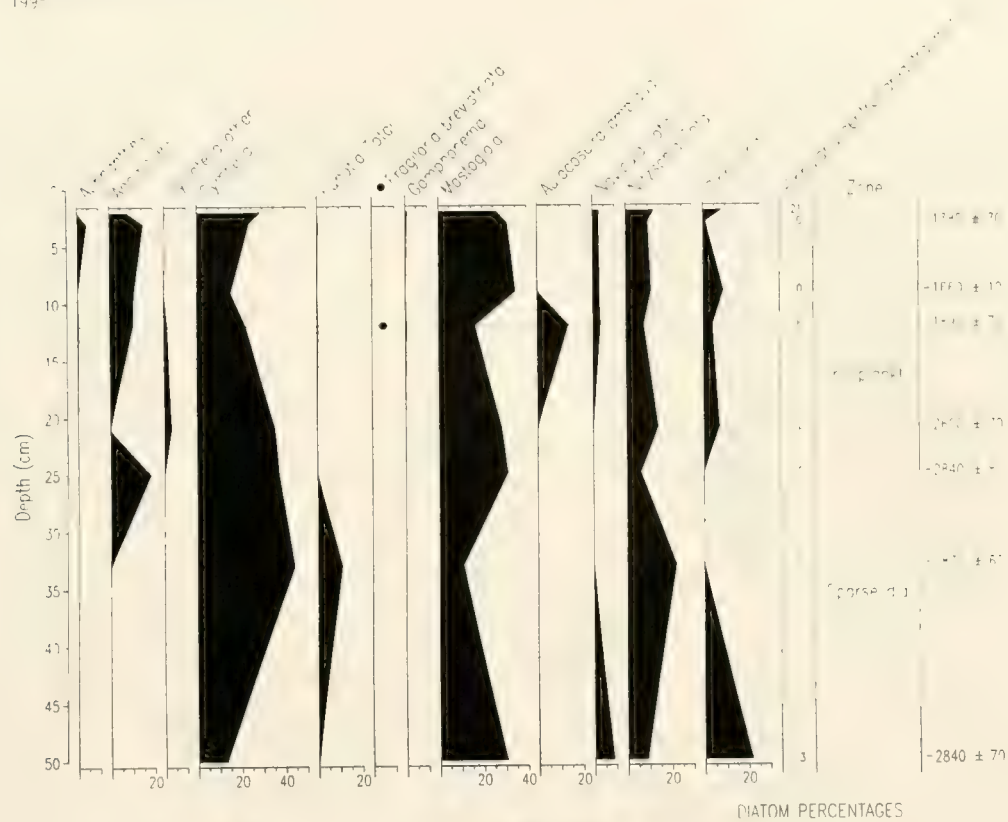
A23H

The diatom assemblage at the A23H site (Text-fig. 10) in Northeast Shark River Slough indicates that alkaline littoral (shallow water), epiphytic (plant clinging) species such as *Mastogloia smithii* v *lacustris*, *Anomoneis vitrea*, *Cymbella microcephala* have dominated since 2840 ± 70 yr B. P. However, for the period after 2600 (?2000) to 1660 yr B. P., circumneutral planktonic diatoms (*Cyclotella*, *Aulacoseira ambigua*, *Tabellaria flocculosa* v *linearis*) appeared and made up more than 10% of the diatom sum. These planktonic species indicate deeper water at that time. The chronology of this deepwater event is concurrent with the interval of abundant planktonic diatoms at Gator Lake dated from 1900 to 1600 yr B. P., suggesting hydrologic changes across the southern Everglades. The inverse relationship of sponge spicule/diatom presence or absence found in Gator Lake sediments, does not hold true at A23H site. Sponge spicules at this site are present only sporadically in intervals when diatoms are abundant. Diatoms are very sparse in the marly peat below 2600 yr B. P.

A06

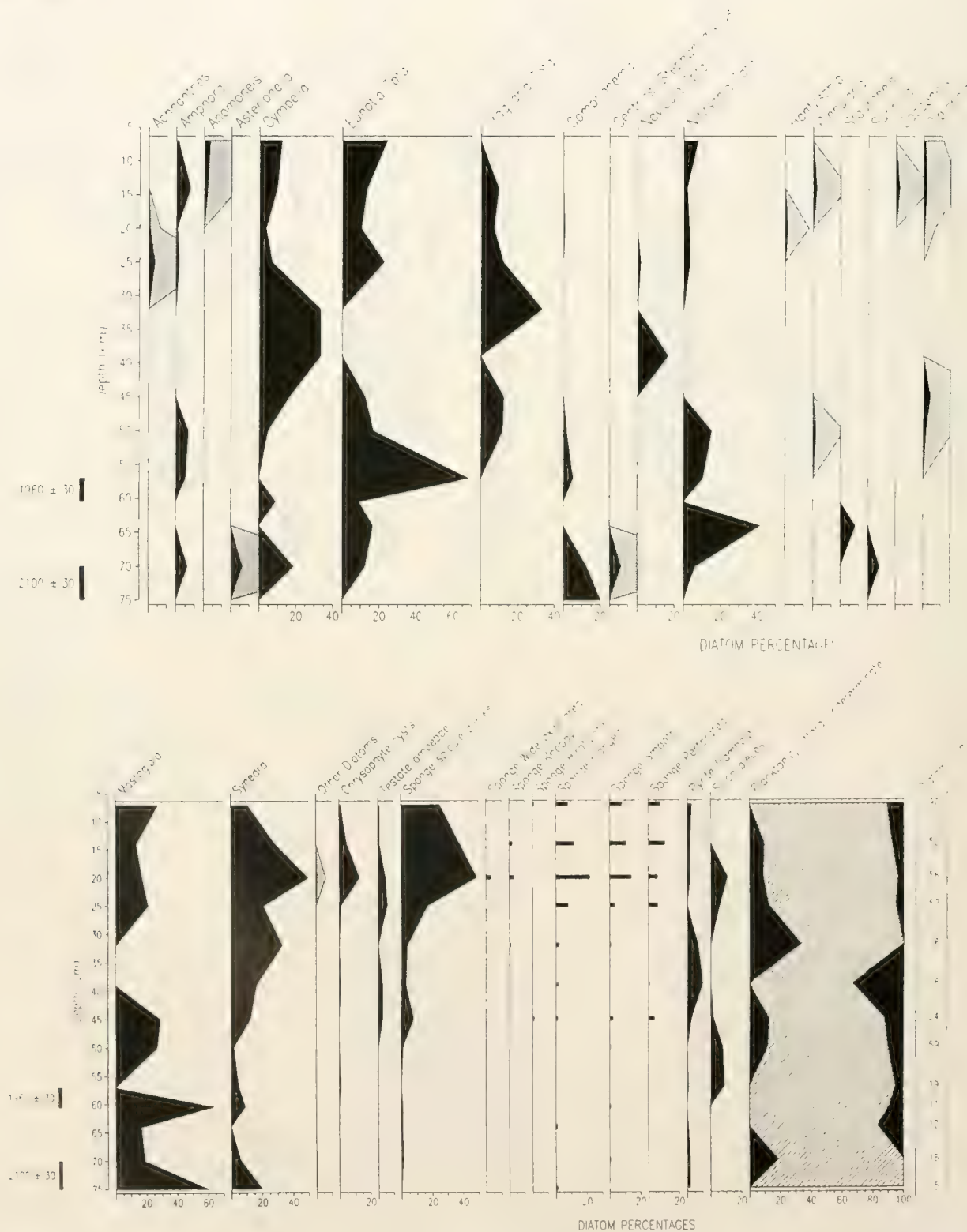
Diatoms are relatively sparse throughout the A06 core and, although entire slides were examined, the highest diatom sum for any level at this site was 156 frustules. The diatom assemblage at the A06 site (Text-fig. 11) in Northeast Shark Slough is dominated mainly by epiphytic alkaliphilic/alkalibiont diatoms from the genera *Mastogloia*, *Amphora*, *Cymbella*, and *Navicula*. However, the basal levels of the core contain epiphytic *Gomphonema* spp. and evidence of alkaliphilic planktonic species including *Asterionella*, *Stephanodiscus*, *Synedra*, and benthic *Surirella* spp. suggesting slightly deeper water after about 2100 yr B. P. Planktonic/benthic diatoms (small *Fragilaria* spp.) are present above 55 cm in the core, but are the dominant taxa only when other diatoms are scarce. At A06 sponge spicules and chrysophyte cysts are most abundant in the top 30 cm of the sediment, the time when diatoms are also most numerous. The number of littoral diatoms increases in the A06 top sediments with much of this increase due to circumneutral *Eunotia*

Site A23H, Diatom Percentages
M. Winkler, August
1996

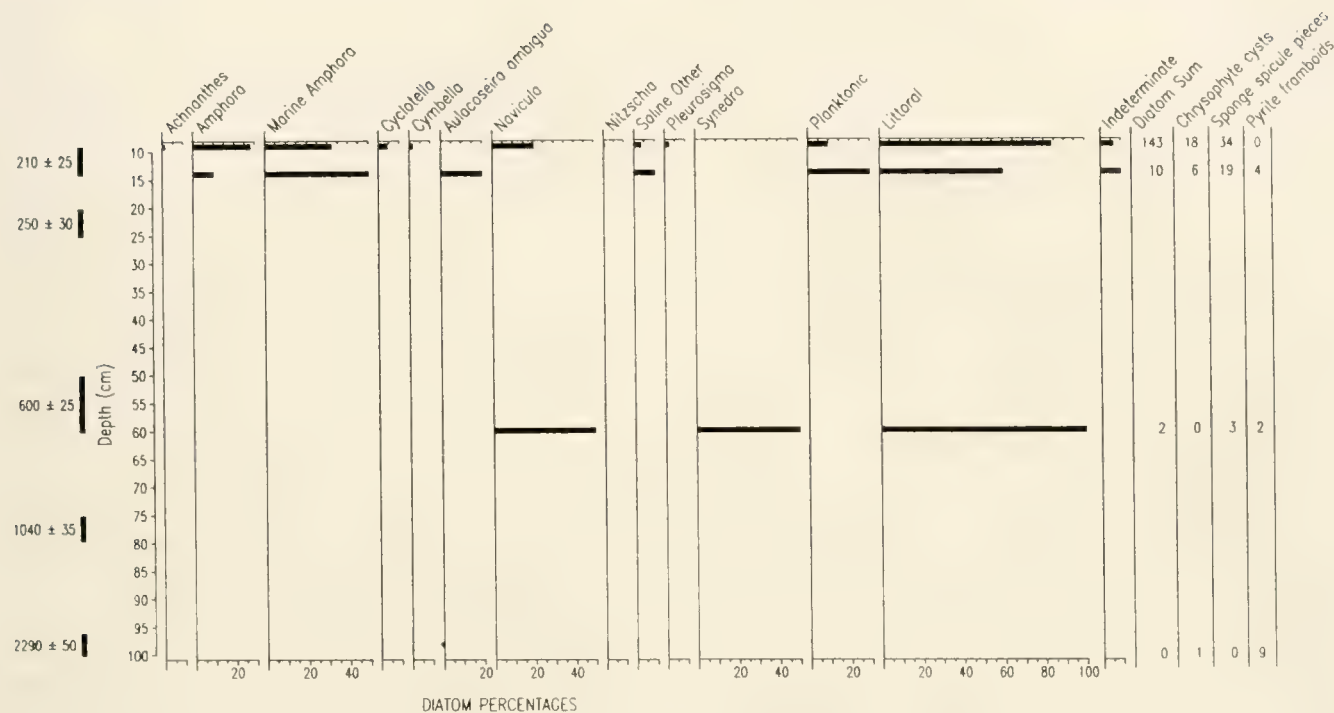


Text-figure 10.—A23H Diatom Percentage Diagram. Solid curves represent actual percentages. Radiocarbon dates are placed to the right of the diagram. Oldest sediment is at the bottom of the column.

A06a-16 in Northwest Slough
 EVERGLADES NATIONAL PARK, Florida
 Custom Percentage
 M. Winkler, Analyst



LIGNUM VITAE KEY, Florida
LV-2 Hiller Core
Diatom Percentages
M. Winkler, Analyst



Text figure 12.—Lignum Vitae Key, Florida, LV2 Diatom Percentage Diagram. Radiocarbon dates are placed to the left of the diagram. Oldest sediment is at the bottom of the column.

and *Pinnularia* species, as well as more alkaline *Amphora*, *Anomoneis*, *Nitzschia*, *Cocconeis*, and *Diplo-neis* spp. A study by Wood and Maynard (1974) may illuminate reasons for the unexpected presence of *Eunotia* and *Pinnularia* diatoms at this site. These investigators analyzed algae trapped in air nets placed on the 7-mile fire tower in ENP. They found that aside from marine algae which had traveled more than 64 km from the sea, there were several species of acid and circumneutral *Eunotia* and *Pinnularia* diatoms in the traps which had probably been airborne from northern and central Florida sites. *Eunotia* and *Pinnularia* are frequently found growing in lakes underlain by acidic sands in northcentral Florida (Sweets *et al.*, 1989; Whitmore, 1989; Sweets *et al.*, 1990). Other aerophilic diatoms found in the air nets included *Mastogloia*, *Amphora*, *Nitzschia*, and *Hantzschia* species, and *Asterionella formosa* (Wood and Maynard, 1974). They also analyzed ENP surface water foams which contained diatoms and theorized that these foams were easily picked up, shredded, and transported by the wind to colonize or recolonize distant sites. The presence of Hurricane Andrew debris at several Everglades sites during our fieldwork in February 1993 (Winkler,

personal observation) illustrates the importance of wind as a factor for distribution of diatoms and other organisms in storm-swept southern Florida.

Lignumvitae Key (LV2)

At Lignumvitae Key site LV2 (Text-fig. 12), diatoms are relatively abundant only in the surface sediments. Marine diatoms, such as marine *Amphora* spp. and *Navicula* spp., *Pleurosigma*, and other saline diatoms (*Triceratium*, *Thalassiosira*, and *Paralia sulcata genuina f. radiata*) comprise the majority of species above 15 cm in the core. Many of the freshwater species, such as *Amphora cf. acutiuscula*, *Cyclotella kuetzingiana*, and *Navicula cf. salinarum* are also found in brackish water. Sponge spicules and chrysophyte cyts are abundant only in the top 70 cm of the core. Pyrite framboids, indicative of reducing conditions, are frequent in the basal sediments of LV2.

Diatom Discussion

The presence of diatoms in the Everglades and the Keys sediments has been either feast or famine. In much of the sediment, diatoms are absent or very sparse. However at times, and at several different sites

(some more than 40 km apart), there are abundant planktonic diatoms indicating high water levels in the southern Everglades. These findings are synchronous and indicate high water between about 2000 and 1600 yr B. P. at site A23 (Text-fig. 10), around 1900 and possibly 1600 yr B. P. at site A06 (Text-fig. 11), and between 1900 and possibly 1600 yr B. P. at Gator Lake (Text-fig. 9). The high water levels in this time period may be concurrent with a local sea-level highstand in Florida Bay (H. Wanless, personal communication, 1998). High water in ENP during this time interval also correlates well with interpretations of high water in northern Guatemala from similar findings of abundant planktonic diatoms in otherwise diatom-barren sediment cores from Laguna de Petenxil in northern Guatemala (Patrick, 1966). This extra-regional hydrologic similarity is not surprising. In an Americas lake-level database which includes late-glacial and Holocene sites, there are similarities in water level changes in lakes within the Caribbean latitudes throughout their history (Winkler *et al.*, 1996b). The Everglades and northern Guatemala are within this latitudinal range. Aside from the diatom-rich period between 1900 and 1600 yr B. P., there are very sparse diatoms before about 1900 yr B. P. at all Everglades sites examined. After 1600 yr B. P. diatoms are either rare at some sites such as Gator Lake, or are abundant shallow water taxa that grow in high nutrient conditions, among heavy macrophyte cover, and/or with heavy algal blooms.

Reasons for the scarcity of diatoms in some wetland sediments might include competition for a limited silica resource. This is unlikely in the Everglades. At only one site (Gator Lake) do diatoms and other siliceous objects (chrysophyte cysts and sponge spicules) have an inverse relationship. At all other sites examined, these siliceous remains are abundant at the same time and disappear together at other times. Dissolution of diatoms and other silica objects may be due to changes in water chemistry. Strong brines, especially Na_2CO_3 and NaCl , and salts of other single valent cations, dissolve silica rapidly. In an experiment by Barker *et al.* (1994), diatoms dissolved in these brines in a matter of days. High pH accelerates diatom dissolution. In fens that receive very alkaline ($\text{pH} > 9$) ground or spring water, diatoms are present in the top sediments, but only highly silicified remains are found a few centimeters downcore (Winkler, unpublished data). Dissolution conditions can be very complex. Some elements, such as iron and aluminum, make complexes with brines and retard dissolution. Seawater incursions at some sites in ENP may destroy freshwater diatoms but may not provide high enough salinities for a long enough duration for growth of saltwater

taxa. In combination with drought which concentrates salts found in freshwaters, water level and water composition changes in the Everglades environment may be too harsh for sustained growth of many organisms. Increased UV- β penetration of surface waters in recent decades, as documented at other sites, may be causing changes in Everglades biota. Diatom growth is suppressed by 40% by UV- β in alpine lakes (Leavitt and Vinebrooke, 1999).

The morphometry of the diatom itself can prevent or delay dissolution—(Barker, 1992; Barker *et al.*, 1994) those diatoms with low surface area to volume ratios remain, while other diatoms dissolve. Turbidity can also cause decreased diatom growth as can excessive nutrient or metal loading. If increased silts and clays and/or macrophyte growth such as water lilies shut out light, diatom growth would be reduced. Dense blue-green algae blooms also shut out light and may interfere with diatom growth. Wood and Maynard (1974) and Gleason and Spackman (1974) have measured blue-green algae mats in excess of 10 cm depth in surface waters. Very warm temperatures (as high as 36°C , Browder *et al.*, 1981) may also favor blue-green algae growth and discourage (or prevent) diatom growth. In temperate lakes diatom growth is dominant during cool spring and fall months (Hutchinson, 1975), giving way to blooms of green and then blue-green algae during hot summer months. Blue-green algae dominance in the Everglades surface waters may be related to their tolerance of high temperatures and high carbonate environments, and to their more efficient utilization of other abundant nutrients. Indeed, some blue-green algae precipitate carbonate (Gleason and Spackman, 1974) and contribute to the formation of marl which covers large areas of the shallow-water Everglades today. The periphyton are the basis of the aquatic food chain upon which most other Everglades organisms are maintained. Some blue-green algae also fix nitrates from atmospheric nitrogen, adding to the already abundant nutrients in Everglades waters which stimulate excess periphyton growth and, at times, lead to anoxic conditions at some sites (especially under low flow conditions). Some blue-greens (e.g., *Microcystis*) secrete phytotoxins which may exacerbate poor growing conditions for other forms of plankton.

Agricultural enrichment by nitrogen and phosphorus in the northern Everglades has been studied by Rader and Richardson (1992). They found that annual primary productivity and algal biomass increased at least 3-fold from nutrient enrichment, but algal diversity did not change (although there were significant species changes and a surprising shift from cyanobacterial mats to dominance by filamentous green algae). However, there was increased diversity of macro-inverte-

brates. The increased minerals identified in our surface samples and interpreted as resulting from agricultural enrichment may explain the abundance of remains of biota in the top sediments at some sites and the dearth of microfossils at depth in some of the cores.

Comparison of Paleoecological Results with Studies of Modern Periphyton Ecology and Distribution

Everglades periphyton taxonomy, chemistry, and distribution have been studied by Van Meter (1965), Gleason and Spackman (1974), Wood and Maynard (1974), Browder *et al.* (1981), Swift (1984), and Swift and Nicholas (1987). Much of their findings are summarized in Browder *et al.* (1994). The dominant algal taxa of the important periphyton communities are listed in Table 16.1 in Browder *et al.* (1994). The periphyton communities have been divided by their relationship to water chemistry into 1). high mineral (carbonate), high nutrient communities, 2). low carbonate, high nutrient communities, and 3). low carbonate, low nutrient communities. The high mineral, high nutrient communities are very alkaline with pH values in excess of 9 and are dominated by carbonate-precipitating filamentous blue-green algae. The low mineral, high nutrient communities are dominated by filamentous green algae in early summer, filamentous blue-greens by late summer and early fall, and in winter by diatoms characteristic of high nutrient waters. The low mineral, low nutrient waters had pH values below 6 and contained a diverse association of desmids and filamentous green algae, and diverse (but not dominant) diatoms characteristic of oligotrophic water and wetlands.

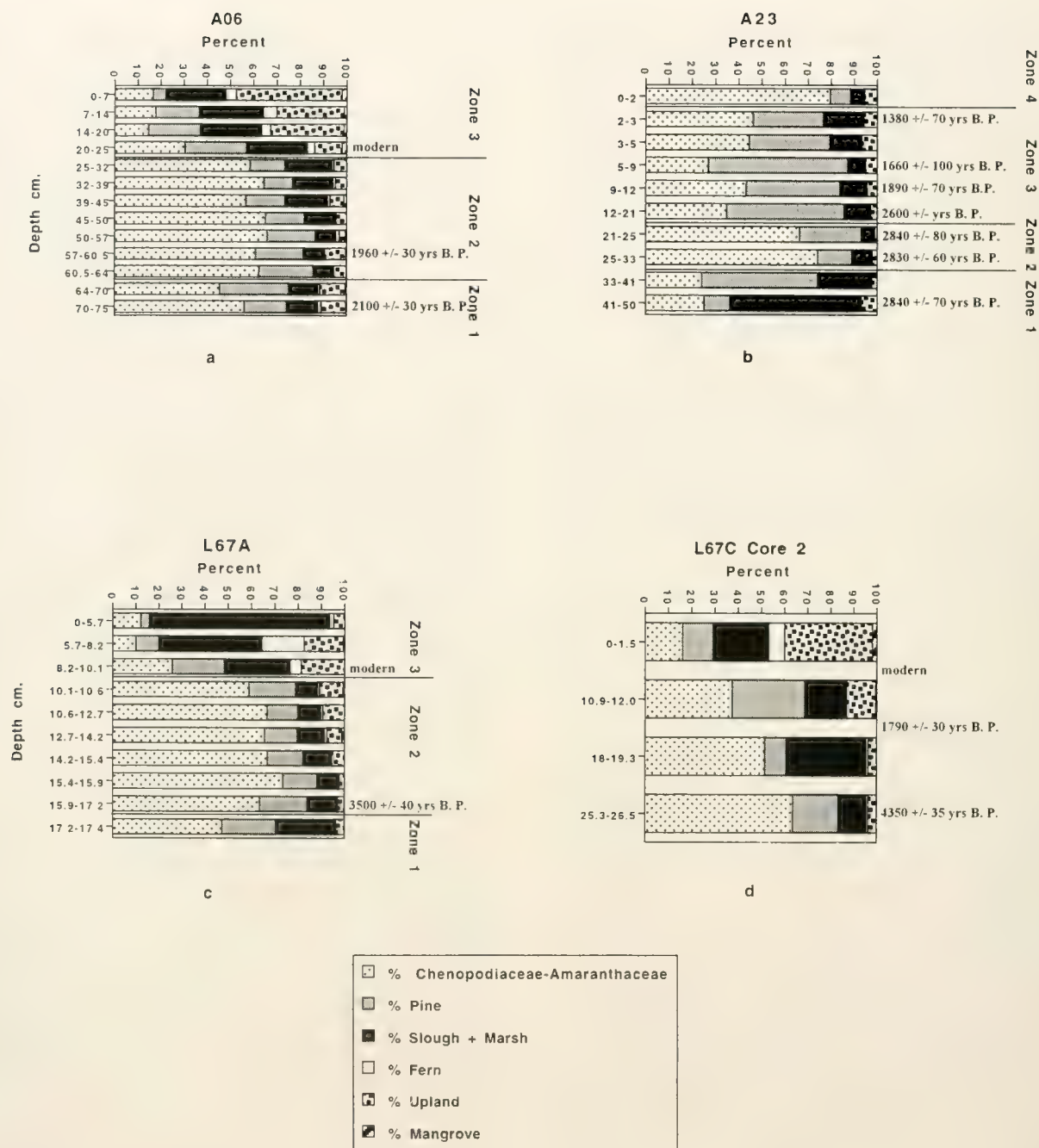
Looking at the spatial variations of the periphyton (Wood and Maynard, 1974; Browder *et al.*, 1994) and specifically, of the diatoms (Whitmore, 1989), it is clear from our core sediment studies that some of the same relationships occur on a temporal basis. For example, *Mastogloia smithii* v *lacustris*, an alkaliphilic diatom found in mesotrophic to eutrophic surface waters, is the dominant diatom in the marls found in the sediment cores (see especially A06 and A23 diatom stratigraphies, Text-figs. 11 and 10). These marls are high carbonate and either high (A06) or low nutrient (possibly A23) environments. pH changes not directly obvious from sediment changes identified in the field or the laboratory may be interpreted by the presence/absence of *Mastogloia* species at specific sites. At other times, however, diatom assemblages unlike those found in the modern sediments were dominant at the sites analyzed and indicate deeper water and different water chemistry from today.

Pollen and Sclereid Analysis

Pollen analytical data from 5 sites, A06 and A23 in Shark River Slough, L67A and L67C in WCA3B, and

Lignumvitae Key illustrate the development of Everglades vegetation. In this section pollen taxa will be divided into 6 groups: Chenopodiaceae-Amaranthaceae (cheno-am), pine, slough and marsh taxa, fern taxa, upland vegetation taxa, and mangrove taxa. Cheno-am is a pollen morphological group comprised of two related families with genera that have similar pollen that is virtually indistinguishable using ordinary light microscopy. Plants of these families are annual weeds of disturbed soil or perennial forbs or shrubs of desert, alkaline, or coastal areas. Based on pore number and grain size more than one species may be represented in our samples. Most grains are between 16–22 μm in diameter and have more than 100 pores, typical of the annual weed genera. Cheno-am pollen found in Everglades sediment has not been assigned to a particular Everglades landscape type because it may be derived via wind transport from habitats far removed from the Everglades, although Loveless (1959b) found that *Acnida cuspidata* (= *Amaranthus cannabinus*), pigweed, invaded sawgrass marsh during drought periods. Cheno-am is often the dominant pollen type found in Everglades sediments. Pine pollen is often co- or sub-dominant with cheno-am pollen. It too is wind transported and may be of extra-local origin, although the pine forests of the Atlantic Coastal Ridge of South Florida may be the most likely source. Slough and marsh taxa include *Nymphaea*, *Sagittaria*, *Utricularia*, Cyperaceae, *Cladium*, *Typha*, *Potamogeton*, *Justicia*, Umbelliferae, and Gramineae. These species represent more local vegetation although grains can be transported by flowing water from their parent plants' growth positions. Cyperaceae including *Cladium* may be underrepresented in Everglades pollen spectra because these species propagate vegetatively as well as by seed and in the case of *Cladium* only older culms produce flowering stalks (Steward and Ornes 1975). Ferns are monolete and trilete spores including Polypodiaceae, *Anemia* sp., and *Osmunda* sp. Ferns may be emergent plants of marshes or understory plants on hammocks. Upland taxa are mainly tree, shrub, vine, or perennial herb species of hammocks, tree islands, and willow heads. These include *Myrica* (wax myrtle), *Quercus* (oak), Myrtaceae (stoppers), and *Cephalanthus* (buttonbush). Mangrove taxa are *Rhizophora* (red mangrove), *Conocarpus* (buttonwood), *Laguncularia* (white mangrove), and *Avicennia* (black mangrove).

Sclereids are structures that provide hardness or rigidity to plant tissues. These structures may remain in sediments after degradation of other plant tissues and some sclereid forms are identifiable to genus. Both *Cladium* and *Nymphaea* have recognizable sclereids which are diagnostic features of sawgrass and waterlily peats (Cohen and Spackman, 1977). *Cladium* sclereids



Text-figure 13.—a-d. Pollen diagrams of A06, A23, L67A, and L67C. Pollen is presented as percentages of total pollen divided into Everglades community groups plus Chenopodiaceae-Amaranthaceae and Pinus. See discussion in text.

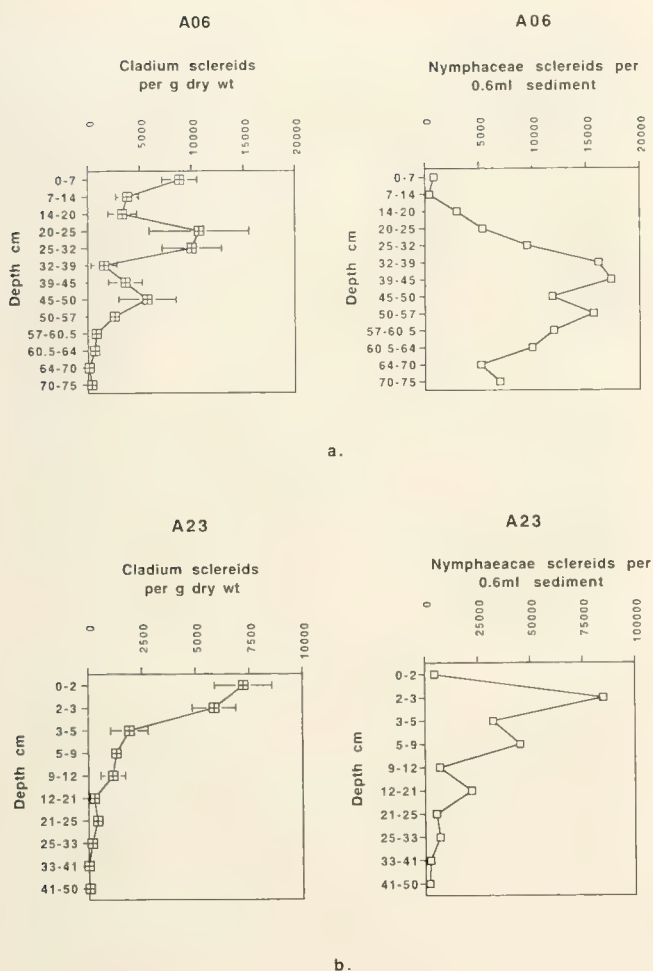
are flat net-like masses with distinctive triangular openings (Plate 1, fig. 5); Nymphaeace sclereids are irregular stellate structures (Plate 1, fig. 6).

A06

The A06 pollen sequence is divided into three pollen zones (Text-fig. 13a). Zone 1, 75–64 cm, is statigraphically marl, more organic at the base and becoming less so at the top of the pollen zone. It has a basal

date of ca. 2100 yrs B. P. Chenopodiaceae-Amaranthaceae dominates at 45–50%, but pine is a secondary dominant. The slough-marsh component and the upland component each comprise ca. 12–15%. Sclereids of both *Cladium* and Nymphaeace occurred at very low concentrations (Text-fig. 14a). Zone 1 represents a low hydroperiod with a shallow mixed sawgrass-waterlily marsh and a drier upland area nearby.

Zone 2, 64–25 cm, transgresses stratigraphic zones.



Text-figure 14.—A06 *Cladium* and Nymphaeaceae sclereids (a); A23 *Cladium* and Nymphaeaceae sclereids (b).

64–57 cm is marl; 57–25 cm is fibrous peat. Marl at 60.5–57 cm yielded a radiocarbon date of c. 1960 yr B. P. The upper part of Zone 2 has no radiocarbon dates, but the change in pollen spectra between Zone 2 and 1 suggests that there is a hiatus; however, the charcoal profile does not show a sharp increase at the top of Zone 2. This zone is characterized by cheno-am dominance (Text-fig. 13a), ca. 60% of the pollen spectrum throughout the zone. At the beginning of Zone 2 slough-marsh and upland pollen groups occur at lower percentages than in preceding Zone 1, but by the end of Zone 2 the slough-marsh component increases to ca. 20% of the total pollen, while the upland component remains at less than 10%. Ferns occur at low frequency and the mangrove component makes a small contribution in the middle of Zone 2. *Cladium* sclereid concentrations rise gradually to a peak at 50–45 cm (Text-fig. 14a), decline and then rise to a higher peak at 32–25 cm. Nymphaeaceae sclereid concentrations rise faster than *Cladium* sclereids and reach a

peak at 57–50 cm, decline slightly, rise to a second higher peak at 45–39 cm, and then decline again. The high percentage of cheno-am pollen may be an indicator of rapidly fluctuating water levels and/or variable hydroperiod. Cheno-ams are early successional weeds which can take advantage of briefly available habitats such as areas alternating between inundation and desiccation over short time intervals. In late Zone 2 at 50–25 cm the slough and marsh pollen group percentages rise and both *Nymphaea* pollen and Nymphaeaceae sclereid concentrations increase. This suggests a longer hydroperiod during this interval.

Zone 3, 25–0 cm is stratigraphically fibrous peat. A radiocarbon date on sediment from 25–20 cm yielded a modern (<~100 years old) date. Zone 3 cheno-am pollen spectra show a sharp decrease, falling from ca. 60% to ca. 30% and then to less than 20% (Text-fig. 13a). The slough-marsh component increases to almost 30% of the pollen total. *Cladium* sclereid concentrations (Text-fig. 14a) peak early in Zone 3 (continuing the trend seen in Zone 2), decline in the middle of Zone 3, and increase again at the top of Zone 3 (the surface sample). Nymphaeaceae sclereid concentrations continue the decline begun in late Zone 2. Upland pollen increases from ca. 15% at the base of Zone 3 to almost 40% at the top of Zone 3 (Text-fig. 13a). The most important species in the upland component is wax myrtle, but buttonbush and *Vitis* (wild grape) also contribute to the increase. The increase in the upland and fern groups may indicate development of a hammock nearby, or may be the result of upland species colonizing the newly available habitat of levee and highway embankments (Leyden in Delfino *et al.* 1994). Mangrove pollen (*Rhizophora* and *Conocarpus*) occurred sporadically in Zones 1 and 2 and was very scarce (mean = 0.28%). In Zone 3 it occurred in every sample and accounted for almost 1.5% (mean = 1.42%) of the total pollen sum. In all zones mangrove pollen is probably derived from distant sources, probably the southwest end of the Shark River Slough. Its increase in Zone 3 may indicate recent deeper incursions of salt water up the Harney and Shark rivers into the Slough accelerating the expansion of mangroves up-slough so that the pollen source area is now a little closer to A06 than in the past.

A23H

The A23H pollen sequence is divided into four zones (Text-fig. 13b). Pollen Zone 1, covers the basal sandy marl deposits (50–33 cm) and is characterized by a high slough and marsh percentage, accounted for almost entirely by *Isoetes* microspores. Nymphaeaceae and *Cladium* sclereids occur at very low concentrations (Text-fig. 14b); *Cladium* sclereids were not found

in the upper sample of Zone 1. Pollen Zone 2 covers two stratigraphic units, a marl layer from 33–25 cm and the lower sample from an organic marl layer, 25–21 cm. It is characterized by cheno-am dominance, 60–70% of the pollen total, and a very low slough-marsh component percentage (Text-fig. 13b). Both *Cladium* and Nymphaeaceae sclereid concentration increase slightly over levels in Zone 1 (Text-fig. 14b). Pollen Zone 3, 21–2 cm covers five stratigraphic units: the upper sample of the first organic marl layer (21–12 cm), a second marl unit (21–9 cm), a charcoal stained marl unit (5–9 cm), a third marl unit (5–3 cm), and the lower sample of the second organic marl unit (3–2 cm). Zone 3 is characterized by cheno-am and pine co-dominance (Text-fig. 13b). The slough-marsh component is variable, but increases to almost 20% by the end of Zone 3. *Cladium* and Nymphaeaceae sclereid concentrations increase sharply in Zone 3 (Text-fig. 14b). Zone 4, the surface sample (upper sample of the second organic marl unit, 2–0 cm) is once again dominated by cheno-ams (Text-fig. 13b). The pine and slough-marsh components percentages are very low. The upland component percentage which increased throughout Zone 3 holds steady. *Cladium* sclereid concentrations reach an all time high, while Nymphaeaceae sclereid concentrations decline precipitously (Text-fig. 14b).

Zone 1 is dominated by *Isoetes* microspores (Text-fig. 13b). *Isoetes flaccida*, the only species mentioned in Long and Lakela (1976) for central and southern Florida today, inhabits sluggish waters. According to Tryon and Tryon (1982) “in the American tropics [*Isoetes*] species grow in lakes, usually in rather shallow water, in pools or in streams, in grassy turf at the border of lakes, in wet open sandy soil. . .” (Tryon and Tryon, 1982: 829). The presence of *Isoetes* does not necessarily imply deep or continuously present water. Pollen and sclereid data indicate low frequencies of *Nymphaea* and *Cladium*/Cyperaceae and a relatively greater frequency of upland taxa. LOI and HLOI evidence of low percent organic and low percent carbonate, microscopic observation of abundant sand grains, *Isoetes* dominance and low pollen concentration, and low occurrences of *Nymphaea* and *Cladium* suggest a seasonally inundated, wet open sandy habitat, with areas of clear standing water, possibly an *Isoetes* marsh. Zone 2 is dominated by cheno-ams both relatively and absolutely. This zone may represent a time of drought or highly fluctuating water levels and hydroperiod.

Zone 3 is characterized by *Pinus* and cheno-am co-dominance with these two taxa switching back and forth as dominant. The slough and marsh group increases fairly steadily early in the zone, declines in the charcoal stained marl unit at 9–5 cm, but recovers in

the upper two samples. Presence of *Nymphaea* suggests at least pockets of deeper water in the area of A23 and a longer hydroperiod than that of Zones 1 and 2. However the deposition of marl layers during the time represented by Pollen Zone 3 indicates radical changes in hydroperiod. *Cladium*/Cyperaceae pollen increases during these marl-short hydroperiod episodes. Zone 3 appears to represent a time when hydroperiods were very variable and the landscape was very patchy with small areas of deeper water sloughs surrounded by marsh and drier areas.

Zone 4, a single sample, represents modern pollen deposition (*Casuarina* is found in this sample). The pollen spectrum is dominated by cheno-ams. Pollen from slough-marsh and upland groups decrease in percent and pollen concentrations of these groups fall precipitously. The Zone 4 pollen spectrum appears to represent a depauperate wet prairie community.

L67A

The L67A pollen sequence is divided into three zones (Text-fig. 13c). Zone 1 is older than 3500 yr B. P. and is characterized by cheno-am dominance less than 50%, slough-marsh group slightly greater than pine at ca. 25%, and a small incidence of upland pollen. Zone 1 is interpreted to represent relatively long hydroperiods. Zone 2 has a basal date of 3500 yr B. P. The top of the zone is undated. Zone 2 pollen spectra are dominated by cheno-am pollen at 60–70%. Slough-marsh and pine groups decrease from Zone 1 percentages and pine is always greater than slough-marsh. By the end of Zone 2 slough-marsh is at its lowest percentage. Upland group pollen percentages increase throughout Zone 2. Fern and mangrove groups appear in upper Zone 2. Zone 2 is interpreted to represent shorter hydroperiods than Zone 1 with drought increasing through time. Zone 3 has a basal modern radiocarbon date. The abrupt change in pollen spectra signals a probable hiatus. Cheno-am percentages decline abruptly to ca. 25% and continue to decline upcore. Pine increases initially, but then also declines upcore. The slough-marsh group percentage triples over Zone 2 values and then increases upcore to dominate the surface sample at ca. 80%. Fern and upland groups increase in Zone 1, but decline in the surface sample. Pollen from mangrove taxa is present only sporadically. Zone 3 is interpreted to represent recently artificially ponded conditions resulting from construction of the Tamiami Trail and L67A and C canals. The L67A pollen diagram resembles those of A06 and L67C in the decline of cheno-ams and the increase in slough-marsh and upland groups pollen in recent samples.

L67C

Only a few samples from L67C have been examined (Text-fig. 13d). These samples resemble those from the A06 core. Cheno-am dominates the pollen spectrum in the oldest sediment; pine is variable, as is the slough-marsh component. The upland component increases over time and is a large proportion of the surface sample. The mangrove component is also most evident in the surface sample.

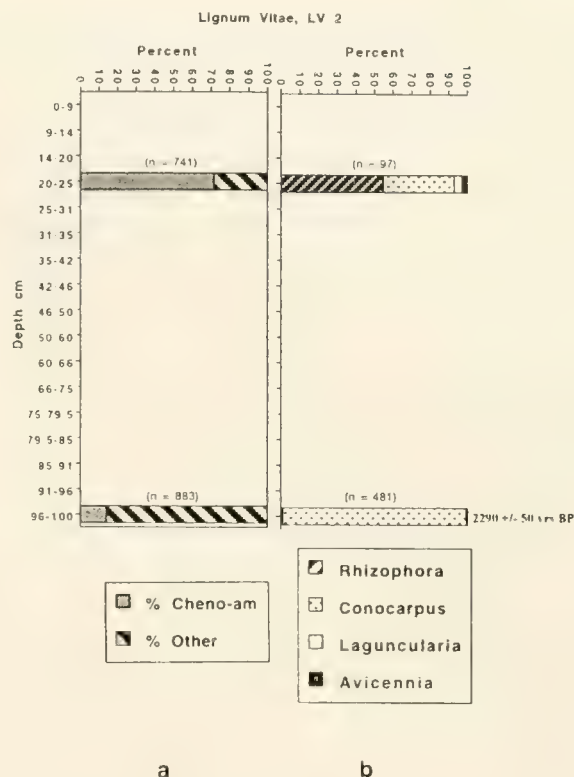
Gator Lake

Subsequent to our coring effort at Gator Lake, we learned that the lake had been cored by a group from the Environmental Engineering Dept. of the University of Florida in Gainesville, Florida (Delfino *et al.*, 1994). This group obtained a 40 cm core from Gator Lake which was ^{210}Pb -dated and found to cover 90 years. The core was used for Hg analysis of the sediment and for pollen analysis (carried out by B. Leyden [Delfino *et al.*, 1994]). The pollen indicated that willow trees expanded near the lake in the last 50 years becoming most abundant since the 1980's. Cheno-am pollen dominated throughout the 90 years covered by the sediment core. Pine pollen decreased in the last 35 years, while pollen from Compositae increased in the last 50 years. The aquatic environment was dominated by *Nuphar* (yellow pond lily) and *Sagittaria* (arrowhead).

Pollen analysis of our longer sediment cores from Gator Lake is in progress. One interesting finding is that *Nuphar* pollen is abundant in Gator Lake sediments from 400 cm depth (about 1500 yr B. P.) to the present. At other sites in the Everglades, *Nymphaea* (white water lily) is the abundant water lily pollen. Pollen analysis also indicates that *Salix* (willow) pollen is only present in the top 40 cm representing the recent several decades at Gator Lake. The lake is presently surrounded by shrub willows. These may have spread from stands that grew on spoil piles from construction in the 1930's and 1940's of the nearby Miami Canal or may have become established after local fires burned the surrounding peat during drought (see charcoal stratigraphy, Text-fig. 5). Willows are known to colonize burned-over peats in the Everglades (Hofstetter, 1974) and the high charcoal in the recent sediments of Gator Lake (Text-fig. 5) suggests that willow growth near the lake may have been initiated after fire (probably during drought or drawdown due to canalization) burned into the deep sawgrass peat around the lake.

Lignumvitae

Lignumvitae Key was chosen as a coring site because it is a protected state botanical site, has a diverse hardwood hammock vegetation, and has an elevation



Text-figure 15.—a and b. Lignum Vitae (LV2) pollen diagrams showing percent Chenopodiaceae-Amaranthaceae versus all other pollen (a) and mangrove pollen divided into constituent species (b). In (b) n = the sum of mangrove pollen.

of close to 5 m, one of the highest keys in Florida Bay. The LV-2 coring site was a relatively shallow (about 10 cm), saline, mangrove-fringed (*Conocarpus*, *Avicennia*) pond (pH 8) separated by an old limestone ridge from a tidal flat. Saltmarsh plants such as *Salicornia* (saltwort) and *Limonium* sp. (sea lavender) were growing on the tidal flat, while the cactus *Opuntia cereus* was found near the pond. Two samples have been analyzed for pollen: 96–100 cm and 20–25 cm. (Text-fig. 15). The 96–100 cm sample is the basal organic sediment which was AMS radiocarbon dated at 2290 ± 50 yr B. P. The 20–25 cm sediment is undated but is within the historic horizon.

The pollen in the younger sample is quite different from that in the older. The younger sample is dominated by Chenopodiaceae/Amaranthaceae (pigweed family) pollen, which constituted only 14% of the older sample (Text-fig. 15a). Most of the pollen in the older sample is *Conocarpus*, a mangrove plant. Considering mangrove pollen only (Text-fig. 15b) *Rhizophora* and *Avicennia* are present in only trace amounts and *Laguncularia* is absent in the older sample; while in the younger sample *Rhizophora* and *Conocarpus* are co-dominant with only minor representation of other

mangroves, *Laguncularia* and *Avicennia*. Pollen of *Alnus*, *Salix*, *Acacia*, *Guaiacum officinale*, and *G. sanctum* is present in the older sample, but not the younger sample. Pollen of *Pinus*, *Taxus-Cupressaceae-Taxodium*, *Juniperus*, *Myrica*, *Schinus*, Anacardiaceae, Palmae, Solanaceae, Tubuliflora Compositae, and Leguminosae are present in the younger sample, but not the older one. Taxa found in both samples include: *Bursera*, Myrtaceae, *Alternanthera/Gomphrena*, and Rhamnaceae.

Of the mangrove taxa *Conocarpus* is the least dependent on immersion in fresh or saline water. It prefers drier ground than the other three taxa and is also a component of the tropical hardwood forest. Its dominance of the older sample suggests drier conditions at 2290 years ago and lower sea level. It is, however, growing abundantly near the coring site now, co-dominant with *Avicennia* (black mangrove). *Rhizophora* is also present today and is replacing *Conocarpus* as salinity of the site increases due to a rising sea level. The sparseness of *Avicennia* pollen in the two samples examined and abundance of *Avicennia* at the site today suggests that this mangrove species has expanded in recent decades at the LV2 site. However, Riegel (1965) states that *Avicennia* produces little pollen which has a restricted local distribution. He considers *Avicennia* pollen percents of 1–2% to indicate presence of the plants at the site and pollen percents more than 5% to indicate dominance at a site.

Chenopodiaceae dominance of the younger sample and the presence of *Schinus* pollen may indicate clearance of some of the island for habitation thus opening up the tropical forest habitat to invasion by weeds. The pollen spectra document the declining presence of *Lignum Vitae* (*Guaiacum* spp.) on the island. While hammock flora is still well-represented, anthropogenic pressures have greatly changed the forest composition on Lignumvitae Key.

Cladocera Analysis

Cladocera (Arthropoda: Crustaceae, Branchiopoda) are small aquatic invertebrates (0.2–2.0 mm) found primarily in fresh water. A few taxa are marine and some freshwater taxa can tolerate brackish water. All of these creatures can swim, but while some forms are primarily free-swimming in open water others are bottom-dwelling or epiphytic. Cladocera are indicators of water chemistry and nutrient status. Loftus *et al.* (1986) found cladocera in the Shark River Slough. Chitinous exoskeletons of cladocera are common components of lake sediment and should therefore be present in marsh-slough deposits in the Everglades.

A06

Chitinous exoskeletal remains of 28 cladoceran taxa were identified from A06 sediments (Table 4). Of these, *Euryalona* and *Oxyurella* have not been found in previous neolimnological surveys of ENP (Loftus, unpub. data, 1993), however they have been found in southern Florida (Crisman 1980, Frey 1982) and it is reasonable to expect to find them in ENP.

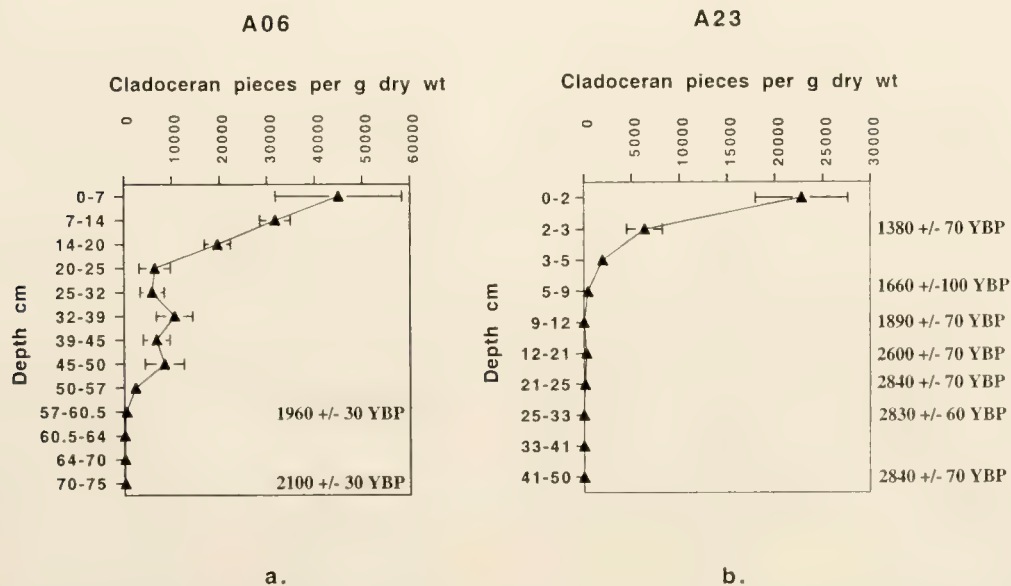
Cladoceran remains occurred throughout the core (Text-fig. 16a). They were very rare in the organic marl at the base of the core and only two taxa were represented, *Alona* spp. and *Chydorus brevilabris*. The number of cladoceran parts and taxa increased slightly in the lower part of the peat, 57–20 cm. Cladoceran parts and taxa increased again beginning at 20 cm and continued at an exponential rate up to the surface, 7–0 cm. One possible explanation for this distribution is post-depositional degradation of cladoceran remains over time although chitinous exoskeletons are known to resist decay in lake and bog deposits over even longer spans of time than are represented by this core (Frey 1964). Oxidation during dry phases would not affect cladoceran remains more than the organic matrix surrounding them, therefore the number of cladoceran remains in a given sample of Everglades peat or marl probably fairly represents the number of cladocera living in the area at the time the deposit formed. Hunt (1952) found that cladocera were never very abundant in the open water of the Tamiami Canal, but that littoral cladocera were found in periphyton growing on emergent and submerged plants. Most of the species listed in Table 4 are littoral substrate dwellers which live on plants rather than in open-water. Thus another explanation for the distribution of cladoceran remains in A06 deposits is that cladocera are tracking periphyton production, which is in turn responding to water level and nutrient changes. The cladoceran data would suggest that periphyton production increased dramatically at this site in the last 50 years. This kind of limnological change would be expected in light of evidence of increased allochthonous nutrients to the site in recent decades.

A23H

Chitinous exoskeleton remains of at least 17 cladoceran taxa were recovered from A23H deposits (Table 5, Text-fig. 16b). Cladoceran remains are so scarce in the deposits from 50–21 cm that little can be inferred from them except that conditions at the A23 site during this time never favored development of a cladoceran assemblage. Rapidly fluctuating water levels and low nutrients could be contributing factors. Periphyton production may have been insufficient in this

Table 4.—A06 cladocera taxonomy and counts. Minimum number (MNI) molts/deaths on counts from four slides per sample.

Taxon	Depth (cm)												
	0-7	7-14	14-20	20-25	25-32	32-39	39-45	45-50	50-57	57-60.5	60.5-64	64-70	70-75
<i>Alona affinis</i>	2	1	2	—	—	1	—	—	—	—	—	—	—
<i>A. verrucosa</i>	4	1	1	—	1	—	—	0.5	1	—	—	—	—
<i>A. setulosa</i>	2	1	—	—	—	1	—	—	—	—	—	—	—
<i>A. rustica</i>	4	—	—	—	—	1	—	—	—	—	—	—	—
<i>A. guttata</i> type	3	1	1	2	—	—	—	—	—	—	—	—	—
<i>A. karua</i> type	—	—	—	—	—	—	0.5	0.5	1	—	—	—	—
<i>Alona</i> spp.	1	—	—	—	—	—	1	1	—	—	—	0.5	—
<i>Euryalona</i>	—	—	1	—	—	1	—	—	—	—	—	—	—
<i>Chydorus brevilabris</i>	1	—	1.5	—	0.5	—	—	—	—	—	—	—	—
<i>Chydorus</i> spp.	—	2	—	1.5	—	1	1.5	—	—	—	1	—	—
<i>Chydorus nitidulus</i> / <i>Ephemeroporus</i>	1.5	0.5	—	0.5	—	—	—	—	—	—	—	—	—
<i>Ephemeroporus hybridus</i>	—	0.5	—	—	—	—	—	—	—	—	—	—	—
<i>E. cf. archboldii</i>	—	—	—	—	—	—	—	0.5	—	—	—	—	—
<i>Dunhevedia</i>	1	—	—	—	—	—	—	—	—	—	—	—	—
<i>Oxyurella</i>	1	—	—	—	—	—	—	—	—	—	—	—	—
<i>Leydigia acanthocercoides</i>	1	—	—	—	—	1.5	—	1	—	—	—	—	—
<i>L. cf. parva</i>	—	—	—	—	—	1	—	—	—	—	—	—	—
<i>Leydigia</i> spp.	1	1	1	—	—	—	—	—	—	—	—	—	—
<i>Alonella excisa</i>	2	—	—	—	—	—	—	—	—	—	—	—	—
<i>Alonella</i> spp.	2	1	—	1	—	—	—	0.5	—	—	—	—	—
<i>Pleuroxus</i> / <i>Alonella</i>	—	—	0.5	—	—	—	—	—	0.5	—	—	—	—
<i>Camptocercus</i>	1	—	—	—	—	—	—	—	1	—	—	—	—
<i>Ilyocryptus</i>	2	0.5	1.5	0.1	—	—	—	—	—	0.5	—	—	—
<i>Grimaldina</i>	1	—	—	—	—	—	—	—	—	—	—	—	—
<i>cf. Eubosmina tubicen</i>	1.5	—	—	—	—	—	—	1	—	—	—	—	—
<i>Ceriodaphnia</i>	0.5	—	—	—	—	—	—	—	—	—	—	—	—
<i>Daphnidae</i>	1.5	—	0.5	—	1	—	—	1.5	—	0.5	—	—	—
<i>Scaphoberis</i>	0.5	—	—	—	—	—	—	—	—	—	—	—	—
Total MNI	34.5	9.5	10	5.1	2.5	7.5	3	6.5	3.5	1	1	0.5	—
Total No. Taxa	21	10	9	5	3	7	3	8	4	2	1	1	—
Total Cladoceran Pieces	193	133	106	29	30	34	32	37	13	10	5	5	3



Text-figure 16.—Cladoceran pieces per gram dry weight for A06 and A23. Error bars = 1 standard deviation based on 4 replicates per sample.

Table 5.—A23H cladocera taxonomy and counts. Minimum number (MNI) molts/deaths on counts from four slides per sample.

Taxon	Depth (cm)									
	0–2	2–3	3–5	5–9	9–12	12–21	21–25	25–33	33–41	41–40
<i>Alona affinis</i>	1	1	—	—	—	—	—	—	—	—
<i>A. circumfimbriata</i>	2	—	—	—	—	—	—	—	—	—
<i>A. costata</i>	—	—	—	—	1	—	—	—	—	—
<i>A. guttata</i>	—	—	—	—	—	—	1	—	—	—
<i>A. intermedia</i>	—	—	—	—	—	—	1	—	—	—
<i>A. rustica</i>	1	—	—	—	—	—	—	—	—	—
<i>A. setulosa</i>	2	1	—	—	—	—	—	—	—	—
<i>A. verrucosa</i>	3	—	—	—	—	—	—	—	—	—
<i>Alona</i> spp.	—	—	3	2.5	—	—	1	—	—	—
<i>Oxyurella</i>	1	—	—	—	—	—	—	—	—	—
<i>Camptocercus</i>	1	—	—	—	—	—	—	—	—	—
<i>Leydigia parvalacanthocercoides</i>	1	1	—	—	—	—	—	—	—	—
<i>Alonella</i> cf. <i>dadayi</i>	2	—	—	—	—	—	—	—	—	—
<i>Alonella</i> spp.	—	—	—	—	—	—	0.5	—	—	—
<i>Chydorus brevilabris</i>	2	—	0.5	—	—	—	—	—	—	—
<i>Chydorus/Pleuroxus</i>	—	—	—	—	1	—	—	—	—	—
cf. <i>Ceriodaphnia</i>	1	—	—	—	—	—	—	—	—	—
<i>Daphnia</i> spp.	—	1	1	—	—	—	—	—	—	—
<i>Ilyocryptus</i> cf. <i>gouldeni</i>	0.5	—	—	—	—	—	—	—	—	—
<i>Ilyocryptus</i> spp.	—	—	1	—	—	—	—	—	—	—
<i>Macrothrix paulensis</i>	1.5	—	—	—	—	—	—	—	—	—
Macrothricidae	—	—	—	0.5	—	—	—	—	—	—
Total MNI	19	4	5.5	3	2	0	3.5	0	0	0
Total No. Taxa	12	4	4	2	2	0	4	0	0	0
Total Cladoceran Pieces	189	38	45	8	5	3	5	0	0	0

area from 2800–1650 years ago to support many cladocera. Cladoceran remains increase in samples from 12–3 cm suggesting more permanent water and/or increased nutrients during this time interval. Cladoceran remains increase exponentially in the uppermost two samples. Because other data suggest lower water levels or shorter hydroperiods during this time, increased nutrients may be a factor in the increase of cladocera at this site.

Sponge Spicule Analysis

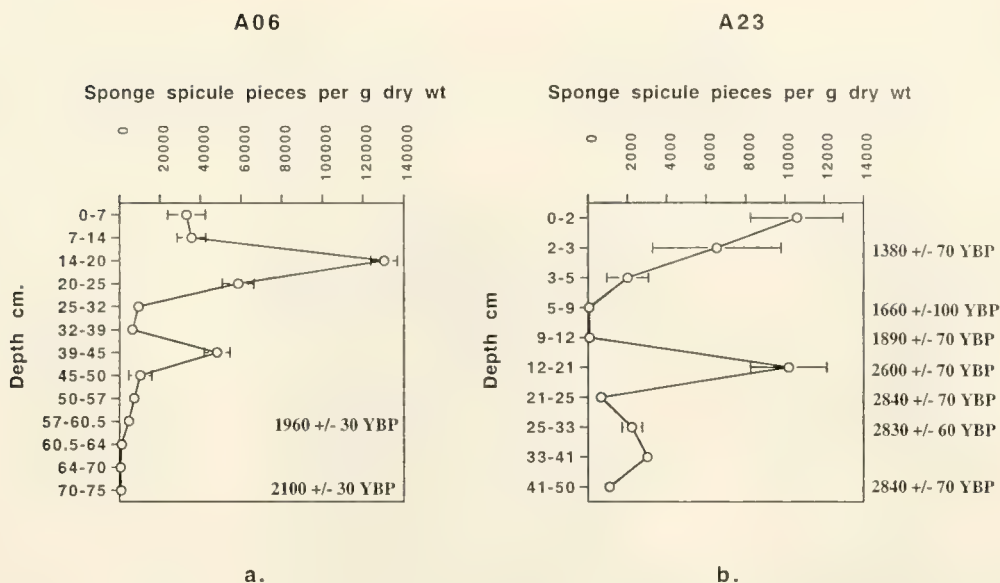
Spicules are the siliceous remains of sponges (phylum Porifera). Pennak states that “Sponges are most common in waters less than 2 m deep . . . and are seldom found in extremely rapid waters” (Pennak 1978). They require hard substrates and rarely grow on mud or silt. Aquatic macrophytes can, however, provide a substrate for sponges to encrust. They are quite sensitive to environmental conditions such as light intensity, pH, conductivity, bicarbonate ion concentrations, and calcium concentrations, and are very sensitive to eutrophication and pollution (Harrison 1974, 1988; Poirrier, 1974; Pennak 1978; Frost 1991). The Everglades would seem to provide ideal habitat for freshwater sponges, but they have rarely been studied (Poirrier, 1976; Harrison *et al.*, 1979) and their role in the Everglades ecosystem is not known; however,

sponges can have a “substantial influence on total nutrient cycling and primary production . . . [and may operate] primarily to limit the availability of materials to other organisms within the food web” (Frost 1991). Because sponges are potentially competitive with periphyton for substrate, their role in the development of the Everglades may be of interest.

A06

Sponge spicules from A06 deposits appeared to be primarily smooth, cylindrical fusiform, amphioxenic megascleres when viewed with ordinary light microscopy (Text-fig. 17a, Plate 1, fig. 3). All megascleres were fragmentary and some showed varying degrees of axial canal widening and degradation. This situation is similar to that of spicular remains studied by Racek (1966) in deposits from Laguna de Petenxil, El Petén, Guatemala. He attributed axial canal widening and degradation to bacterial reduction of gypsum in the sediment releasing $\text{Ca}(\text{OH})_2$ which dissolved hydrated silica. The degraded condition of A06 megascleres suggests that this process may have occurred in the Everglades in the past. Increased amounts of $\text{Ca}(\text{OH})_2$ in the sediment from bacterial action may also be operative in the dissolution of diatoms.

Some A06 megascleres were virtually complete, missing only their tips. Measurement of 50 virtually



Text-figure 17.—Sponge spicule pieces per gram dry weight for A06 and A23. Error bars = 1 standard deviation based on 4 replicates per sample.

complete spicules from 20–14 cm depth indicates that megascleres average at least 396 μ m long (range 300–476 μ m, S.D. 43 μ m) by 30 μ m w (range, 16.5–43 μ m, S.D. 6.4 μ m). Several taxa have smooth megascleres in this size range: *Ephydatia fluviatilis*, *Spongilla alba*, and *S. cenota* (Frost 1991). Unfortunately, identification is based on microscleres and gemmoscleres, which are scarce in A06 deposits. The few gemmoscleres seen resemble those of *Spongilla lacustris*, but the spines are not very well defined. These spicules are slightly bent cylindrical fusiform amphioxes from 60–70 μ m l with sparsely, but $\pm$ uniformly distributed, short, broad-based spines (Plate 1, fig. 4). With light microscopy the axial canal is visible running lengthwise within this spicule type. The absence of definite microscleres and the large size of the megascleres suggest that *E. fluviatilis* may also be present, but its birotulate gemmoscleres were not seen.

Sponge spicule pieces are present in every sampling increment of the A06 core, but they are rare in the dark organic marl (75–57 cm, Text-fig. 17a). Two peaks in sponge spicule pieces are, however, apparent in the peat: one at 45–39 cm and another at 20–14 cm, when diatom frustules are also most numerous.

A23H

Sponge spicules were found throughout the A23 deposits (Text-fig. 17b). A23 spicules were similar to those already described for A06. They occurred in low numbers in deposits from 50–21 cm with a small peak at 41–33 cm. A very large peak occurred in the organic marl unit from 21–12 cm at the same time that plank-

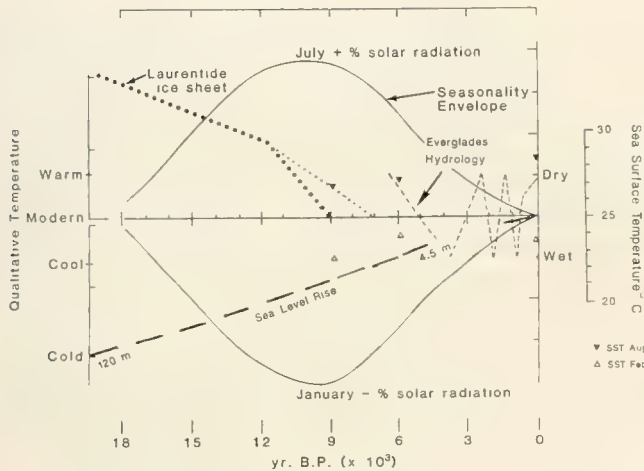
tonic diatoms occur. From 12–5 cm, spicules were very rare. Then from 5 cm up to the surface sponge spicules increased exponentially as did *Cladium* scleroids and cladocera pieces. There was no numerical relationship among these three biotic indicators in earlier levels, therefore the increase in all three indicators may reflect some structural or functional change in the marsh ecosystem, possibly increased nutrients.

HOLOCENE CLIMATE ON THE FLORIDA PENINSULA

Our study of sites in the southern Everglades indicates a shift from a dry to wet climate in the middle Holocene at about 5000 yr B.P. which initiated formation of the peat-forming Everglades. Similar changes were taking place circum-Caribbean (Text-fig. 18). We looked for continental- and regional-scale factors which would effect this dramatic change. Climatic changes in North America during the Holocene were determined by collapse of the Laurentide ice sheet, the position of sea level due to ice retreat, the relative amounts of land and sea in the hemisphere, changes in the orbital parameters of the Earth which determine insolation variations and seasonality, volcanic eruptions, and other boundary conditions (Text-fig. 19). Changes in the North Atlantic thermohaline circulation pattern would also affect what happens on land in southern Florida. Sea surface temperatures adjacent to the Florida peninsula are important in determining the amount of annual and seasonal precipitation with warmer water causing greater rainfall. In our investigation of the cause of the change from dry to wet



Text-figure 18.—Time and space comparison of qualitative hydrologic changes (Wet/Dry) from regional paleoecological data. Sites range from northern to southern (ENP sites) Florida and from Haiti in the Caribbean to northern Guatemala. Timing of wet/dry transitions may not be as definite as the line separating them suggests at some sites.



Text-figure 19.—Late-glacial and Holocene climate change diagram. The seasonality envelope illustrates changes in % solar radiation in July (+) and January (–) throughout the last 18,000 radiocarbon years (possibly 21,000 years if compared to the Uranium-Thorium coral chronology) determined by changes in the orbital parameters of the Earth (the Milankovitch cycle). It demonstrates that at about 12,000 through 8,000 yr B. P. seasonality was different from today because the Earth was closest to the sun in July (today Earth is closest to the sun in January) and summers were warmer and winters colder than modern in middle latitudes. The Laurentide ice sheet melted from the continent by about 7000 yr B. P. (Dyke and Prest, 1987). Sea Surface Temperature scale (SST, closed triangles: August; open triangles: February) is on right and indicates from foraminifera changes in ocean cores that SST (southeast of South Florida) was slightly warmer in winter than modern at about 6000 yr B. P. (Ruddiman and Mix, 1993). Sea Level Rise, the lower dashed-line curve, reaches to 4.5 m by about 5000 yr B. P. (Dyke and Prest, 1987; Wanless *et al.*, 1994) but the rate of rise varied after about 3000 yr B. P. The Everglades peat was initiated at about 5000 yr B. P. possibly due to increased winter precipitation because of the warmer SST's and the rising sea level. The changes in Everglades hydrology (Wet or Dry) interpreted from our results is shown from 5000 yr B. P. to the present. Diagram modified from Kutzbach and Street-Perrott (1985).

climate in Florida and the Caribbean region at about 5000 yr B. P., we consider two mechanisms: sea level rise and changes in ocean temperatures after collapse of the Laurentide ice sheet. Calculations of orbital conditions at 5000 yr B. P. shows maximum insolation in early fall. Sea surface temperatures would therefore be higher at that time and the incidence of tropical cyclones would increase. Increased storminess would bring more moisture to the Florida peninsula. Fossil data from foraminifera in ocean cores from the region (Ruddiman and Mix, 1993) indicate that sea surface temperatures southeast of the Florida peninsula did change at about that time. Sea surface temperatures were about 0.3°C warmer than modern in winter 6000 yr B. P., but about the same as modern (~28.5°C) in summer. In addition, because the S. Florida peninsula is relatively narrow with low relief and has a porous

limestone aquifer, sea level rise during the Holocene was important to initiation of Everglades peat. Sea level was 120 m lower than the present mean sea level at the last glacial maximum (18,000–21,000 yr B. P.), had returned to about 6.2 m below modern levels by 5500 yr B. P. (Fairbanks, 1989; Wanless *et al.*, 1994), to about 4.5 m below modern levels by 5000 yr B. P. (Dyke and Prest, 1987) and to about 3 m below modern levels by 4000 yr B. P. (Colquhoun and Brooks, 1986). Rising sea level would raise the freshwater table in the Everglades wetlands (the freshwater aquifer overlies saltwater) and would slow sheetflow through the Everglades from the north.

Most sites throughout Florida indicate drought before 5000 yr B. P. and wet conditions after that time (Text-fig. 18), regardless of their proximity to the sea, indicating that changing climatic conditions such as increased precipitation due to rising sea surface temperatures in the middle Holocene (Ruddiman and Mix, 1993) especially in winter, may have been equally important as sea level rise in initiation of the Everglades landscape. Furthermore, increased precipitation in winter in the middle Holocene (about 6000–5000 yr B. P.)—winter today being the driest time of the Everglades year—may have provided the needed increased effective moisture for peat to accumulate at many sites. Other global-scale climatic events such as more numerous El Niño years since 5000 yr B. P. (Sandweiss *et al.* 1996) would also increase precipitation to the southern peninsula of Florida as it does today (Winkler *et al.*, 1999).

The interaction of rising sea level and increased precipitation resulted in long hydroperiod in low-lying areas and the accumulation of peat, especially in the Everglades Depression south of Lake Okeechobee. Higher elevation areas adjacent to the Everglades Depression did not accumulate peat until sea level rise raised the water table to intersect local low points. Once peat is present on the landscape it retards waterflow, further increasing the hydroperiod (water residence time) at a site. The presence of peat would also raise the water table at a site, separating the water in the peat from the carbonate-rich Everglades aquifer and thereby changing the chemistry of the site. The peat would then be watered by a larger proportion of water from rainfall than by groundwater or surface flow. The formation of barrier beaches surrounding southern Florida and the topography within the old limestone bedrock, also affect the rate of waterflow through the Everglades drainage and the accumulation of freshwater peats. Some of the higher elevation areas may never have accumulated peat. Instead seasonally wet prairies developed on short hydroperiod, higher elevation sites and marl deposition began.

Our evidence for an increase in effective moisture in winter at about 6000–5000 yr B. P. and initiation of peat deposition in the southern Everglades supports the Genesis1 climate model simulations for the Caribbean region which show that in winter (December, January, February) at 6 ka, surface temperatures increased by 0.74°C, precipitation increased by 0.79 mm/day, and $P - E$ increased by 1.2 mm/day, compared to modern values (Thompson and Pollard, 1995).

What we probably see in the Everglades today is a landscape that has become increasingly fragmented after 2900 yr B. P. by shrinkage of the peat-based plant communities and expansion of the drier plant communities. The modern dry conditions are further exacerbated by anthropogenic drainage, canalization, and drawdown of freshwater.

IMPACTS FOR LAND MANAGEMENT AND DECISION-MAKING

Today the Everglades hydrologic environment is increasingly uncoupled from climatic changes as water is artificially sequestered in some parts of the historic Everglades and diverted from other parts. Recent anthropogenic nutrient and hydrologic changes seem to favor periphyton production leading to widespread marl deposition in contrast with climate- and sea-level-induced changes over the past 5 millennia when standing deepwater peats formed. However, some of our cores (e.g. A23, Ever6, and 9-Mile) show that some areas have experienced marl production only and have, therefore, always had shorter hydroperiods. These marl prairies are important habitats for native Everglades fauna, notably the Cape Sable Sparrow. Therefore, simply increasing the amount of water standing over the whole Everglades by artificially maintained long hydroperiod/high water levels will not preserve the natural Everglades. Neither will suppression of wildfires, which are necessary to the maintenance of the mosaic landscape by burning off peat and naturally lowering the topography so that ponds and sloughs can develop and provide sites for peat to accumulate again. A rewatering plan must include both wet and dry seasonal cycles in order to preserve the natural landscape of the southern Everglades—a shifting mosaic of wet and dry communities in space and time—as a functional habitat for both plants and animals. The mosaic landscape of the Everglades may become less complex if long-term water management does not take into account the natural dynamics of the hydroscape and the topographically variable landscape which offers diverse habitat for flora and fauna.

Sea-level rise is another confounding factor that must be taken into account in an Everglades rewatering plan. There is pollen (mangrove taxa replacement)

and diatom evidence of sea-level changes that correlate with findings in cores from Florida Bay. Chemical analyses of C111 sediments suggest a salt water incursion several millennia ago at sites east of Taylor Slough followed by a subsequent change to fresher water as channels were closed off. Therefore, changes in rates of sea-level rise and in the topography of Florida Bay, both volatile processes, should be considered during water delivery to the lower Everglades.

CONCLUSIONS

Paleoecological study tells us that the Everglades landscape was (and is) a shifting mosaic of biotic communities initiated at about 5000 yr B. P. when the southeastern U. S. and a broader Caribbean region underwent transition from dry to wet climate. Our results indicate that most sites alternated between deposition of wet peat or drier marl at times throughout their existence. These facts document that the modern mosaic landscape existed in time as well as space for at least five millennia. Fire and low, drought-induced, water levels are critical natural structuring agents in the development of the Everglades landscape but these events cause severe sediment decomposition. Due to fire and drought there are probably no marsh or prairie deposits with complete paleostratigraphic records and it is therefore necessary to piece together the history of the Everglades from many cores. These cores should be well dated because hiatuses in the record are not always stratigraphically obvious. A wide variety of physical and biotic parameters should be examined as well because chemical and hydrologic extremes also result in gaps in the biologic record.

Most plant communities in the past were similar (inferred from pollen and sclereid analyses) to those present in today's landscape, although in the course of our research we found at least one habitat type, an *Isoetes* marsh, which is not recognized in the modern Everglades. *Isoetes* marsh is found today on the Yucatan Peninsula, but is not listed as a biotic community in any of the vegetation surveys of the historic Everglades. Other vegetation changes, including the periphyton composition, have been caused by nutrient and trace element increases from land use changes in the last 50 or so years and the introduction of aggressive exotic plant species. However, dominant diatoms found in surface marls were also found to be the same taxa that dominated in ancient marl sediments. Cladoceran assemblage changes appear to correlate with nutrient-driven periphyton changes in top sediments.

Pollen also provided evidence of changes in mangrove species in Lignumvitae Key in Florida Bay. There *Rhizophora* is replacing *Conocarpus* as the salinity of the site increases due to sea level rise. At that

site pollen also documents the declining presence of *Lignum Vitae* trees on the island and other hammock forest changes due to anthropogenic pressures including the introduction of exotic plant species.

Planktonic diatom increases documented a wet period between 2000 and 1600 yr B. P. at several sites over a broad region of the Everglades. This wet period appears to correlate with an increase in the rate of sea-level rise suggesting that sea-level changes affect sites far inland in the southern Everglades as well as sites in and near Florida Bay. However, although sea-level rise continued, freshwater at inland sites lowered after 1600 yr B. P., as indicated by subsequent marl sediments and increases in epiphytic diatoms.

The recent hydrologic environment of the Everglades and ENP appears to be one of marl deposition. Relatively old dates on sediments near the upper part of cores suggest that in the last centuries there were large water-level changes leading to decomposition and loss of recent sediments during times of drought and also possibly flushing of sediments out of the system during times of high flow. The lack of accumulation of modern peat sediments except in places where water pools due to human structures, the concentration of charcoal particles in top sediments, the algal floc and marl found in recent sediments, and the old dates of near-top sediments, suggest this change in hydrologic regime.

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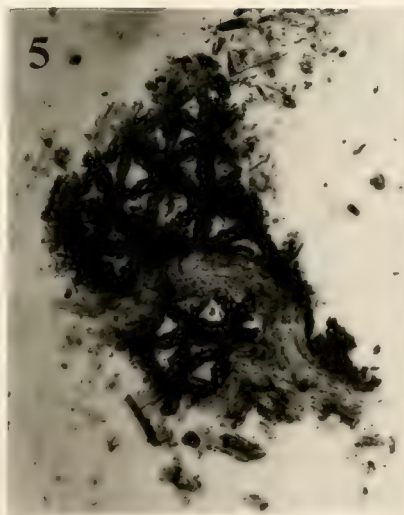
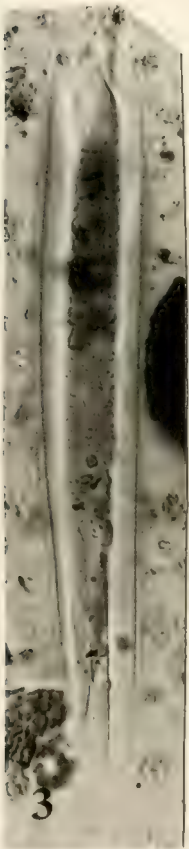
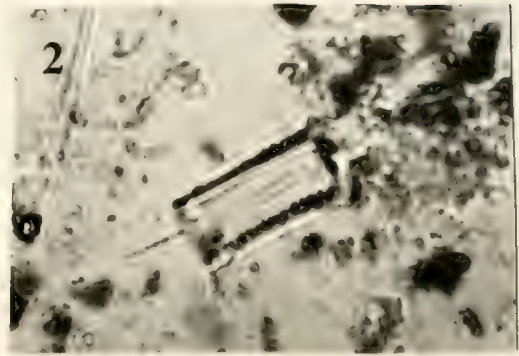
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EXPLANATION OF PLATE 1

Figure	Page
1, 2. <i>Aulacoseira</i> , possible new diatom species, Gator Lake, 471 and 571 cm, $13 \times 5-6 \mu\text{m}$, with parallel rows of very fine pores (almost unresolvable at $1000\times$ magnification), note also long spines.	77
3. Unidentified sponge megasclere, A06, 14-20 cm, $266 \mu\text{m}$ long.	90
4. Unidentified sponge gemmosclere, A06, 20-25 cm, $70 \mu\text{m}$ long.	91
5. <i>Cladium</i> sclereid piece, A06, 0-7 cm, longest dimension $333 \mu\text{m}$, triangular openings <i>ca.</i> $23 \mu\text{m}$	84
6. Nymphaceae sclereid, A23, 33-41 cm, $600-670 \mu\text{m}$ long.	84



CHAPTER 6

A POLLEN ZONATION OF SOUTHWESTERN FLORIDA USING MULTIVARIATE STATISTICAL METHODS AND ITS APPLICATION TO TWO VERTICAL SEDIMENTARY SEQUENCES

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ABSTRACT

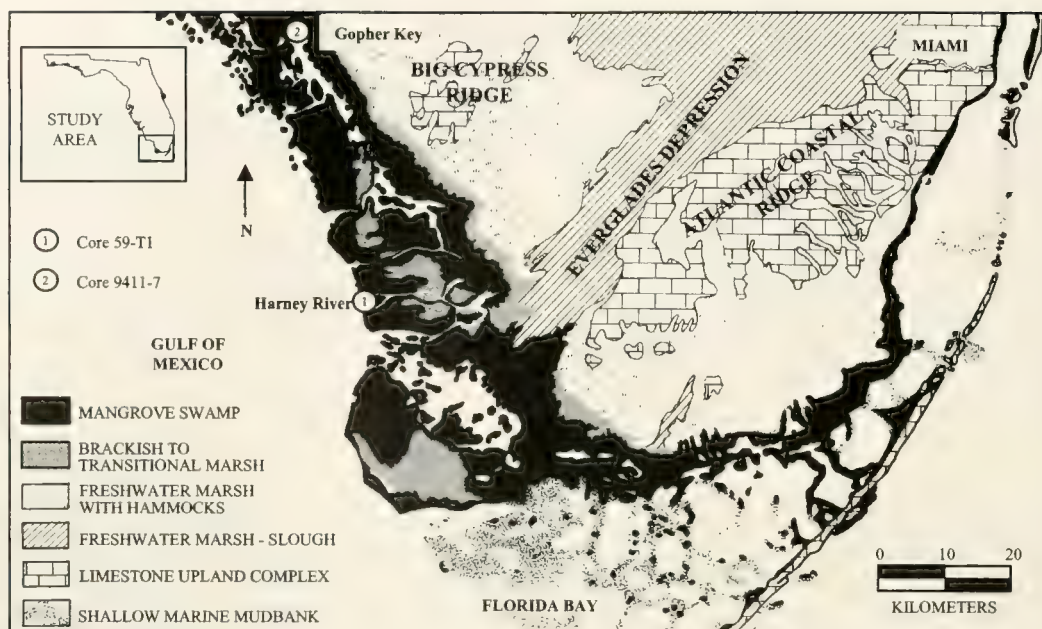
Extensive and reliable modern analogs are the key to palynological assessments of habitat change. This study uses multivariate statistical techniques to reevaluate surface pollen distributions within Everglades National Park, South Florida. Results indicate that multivariate techniques provide a sensitive and informative measure of variations in the distribution of pollen and spores. The distribution of pollen and spores in surface sediments of southwest Florida were grouped into five distinct clusters, or pollen zones, containing a total of 10 sub-clusters that help delineate subtle differences within each zone. These pollen zones are: 1) mangrove swamp, 2) brackish marsh, 3) freshwater marsh, 4) headwater marsh, and 5) upland complex. The spatial distribution of these pollen zones strongly corresponds to the major physiographic provinces of the area. Cluster analysis indicates that individual taxa typically are not environmentally restricted and, in most environments, there is no single indicator species because of overlapping ranges. The results generated from the analysis of surface assemblages are applied to two vertical sedimentary sequences to interpret past environmental changes. Results show that these methods can be used to identify broad environmental changes (*i.e.*, the overall late-Holocene transgression of South Florida) and can differentiate among different mangrove swamps where time integration of *in situ* samples has occurred. The method is limited in its ability to differentiate short-lived changes in coastal configuration (*i.e.*, sea-level oscillations) as long as the overall environment remains in close proximity to the coastal zone. In these cases, detailed sedimentologic work, combined with palynological analysis is required, especially where sediment reworking has occurred.

INTRODUCTION

Pollen and spores incorporated into the sediment record of the coastal systems of South Florida can provide detailed information about environments of deposition. However, the variety of pollen and spore types present in most samples makes it difficult to compare and group assemblages by visual inspection of frequency histograms. Multivariate statistical methods provide more robust techniques for comparing and grouping surface pollen sites, and also permit the simultaneous investigation of multiple sample sites containing several taxa. Such techniques have been used successfully for ecological interpretations at the regional scale elsewhere: see, for example, Birks *et al.* (1975). To date, however, such methods have not been applied in South Florida, even though the vegetation communities have a distinct spatial distribution that is strongly related to salinity, hydroperiod, elevation, and substrate, and are likely to be amenable to such analyses. Moreover, given the considerable attention that has been, and is now being, directed towards the use of palynological data in interpreting the paleoecology of vertical sediment sequences in the area (Riegel, 1965; Spackman *et al.*, 1966; Kuehn, 1980; Bartow *et*

al., 1996; Meeder *et al.*, 1996; Brewster-Wingard *et al.*, 1997; Willard and Holmes, 1997; Winkler *et al.*, 1998), such methods have great potential to associate vertical sequences of assemblages with surface pollen and spore groups in order to interpret paleoenvironmental changes through time.

The purpose of this study is two-fold. First, to delineate surface pollen zones in Everglades National Park, South Florida, using multivariate statistical methods. The objectives here are to (1) provide an objective model for interpreting the distribution of pollen and spores in surface sediments, (2) demonstrate the sensitivities of cluster and discriminant analysis in delineating surface pollen clusters, and (3) provide a framework for paleoecological reconstructions in South Florida. Then second, to use the objective pollen zonation to analyze and interpret two vertical sedimentary sequences, one from the Harney River, the other from Gopher Key, in terms of late Holocene environmental conditions. With these objectives, the paper is structured in two parts: pollen data for contemporary sediments and their analysis are presented first; details of the vertical sequences, pollen counts, and their analysis, second.



Text-figure 1.—Major physiographic provinces of the South Florida peninsula (modified from Wanless *et al.*, 1989). Cores discussed in Part B are located.

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STUDY AREA

South Florida is part of the broad, Florida platform (Parker and Cooke, 1944). Although presently attached to the North American continent, the South Florida peninsula is a partly inundated carbonate platform removed from most continental influences (Wanless *et al.*, 1989). Sea level has flooded the platform resulting in an expansive shelf margin to the west and a narrow, steep-sided margin to the south and east. The uppermost rock units in the study area are of Tertiary and Quaternary age (Puri and Vernon, 1959). The north-

west portion of the study area is underlain by the Pliocene Tamiami Formation, a calcareous sandstone to sandy limestone (Parker and Cooke, 1944). The Big Cypress Ridge area is underlain by shallow reefal limestones of Pliocene age (Meeder, 1987). The remaining portions of the study area are underlain by the Pleistocene Miami Oolite (Parker *et al.*, 1955; Hoffmeister *et al.*, 1967). Unconsolidated Holocene sediments blanket much of the bedrock surface. Holocene carbonate, organic and siliceous sediments of biogenic origin are forming and accumulating, and quartzose sands are being supplied by littoral transport and by dissolution of limestones (Wanless *et al.*, 1989). The gentle southerly slope of the bedrock surface results in an increase in the thickness of unconsolidated Holocene sediments seaward. Local differences in the thickness and distribution of Holocene sediments can be attributed, in part, to hydrologic and topographic variability in which the preexisting limestone surface plays a fundamental role (Wanless *et al.*, 1995).

PHYSIOGRAPHY

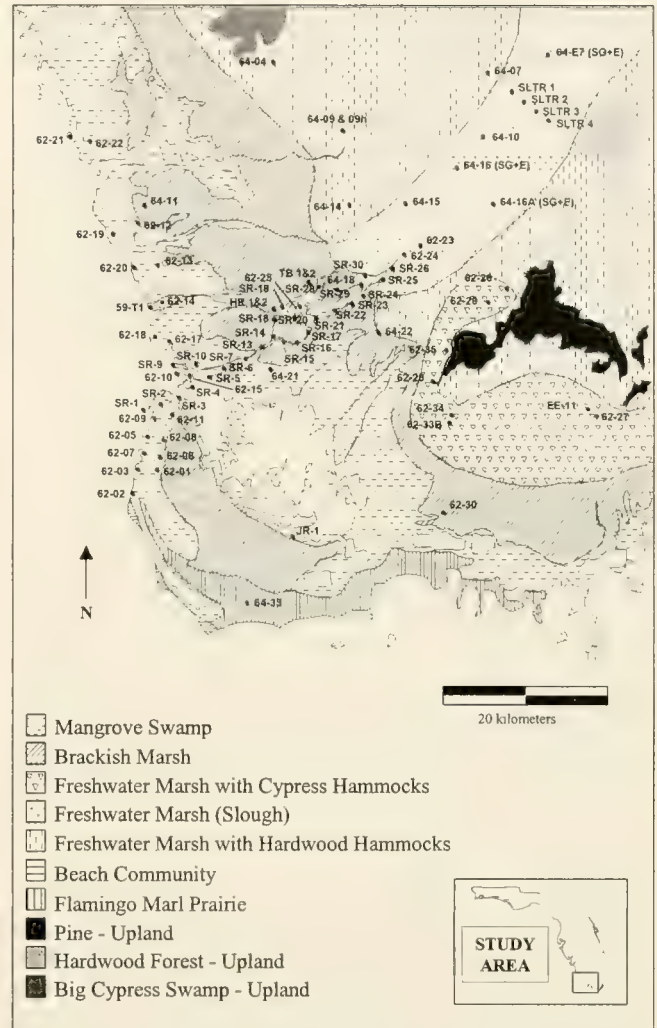
The distribution of pre-Holocene bedrock highs and thick accumulations of Holocene sediments define the major physiographic provinces of the South Florida peninsula (Text-fig. 1). The Everglades depression extends southward through the center of South Florida and is bounded by exposed Pliocene limestones of the Big Cypress Ridge to the west and the Pleistocene quartz sand and oolitic limestone of the Atlantic Coast-

al Ridge to the east (Text-fig. 1). The broad Everglades depression carries fresh water flow southward from Lake Okeechobee to the sea via the Shark River Slough complex (Text-fig. 1). The Everglades depression is underlain by Pleistocene lagoonal deposits termed the bryozoan facies of the Miami Limestone by Hoffmeister *et al.* (1967). The depression is choked with Holocene freshwater peat and calcitic mud deposits (Wanless *et al.*, 1989). A natural coastal dam of mangrove peat and storm-levee marl inhibits saline intrusion into the depression. The oolitic limestone ridge of the Miami Limestone crests 2–6 m above sea level, extends north-south from north Miami to the south, where it then curves westward. The Atlantic Coastal Ridge is cross-cut by numerous fossil tidal channels. These channels form swales that are filled with quartz sand and peat and served as conduits for fresh water flow through the ridge prior to drawdown of Everglades water levels in the early 1900's (Wanless *et al.*, 1989).

In addition to the physiographic units defined by Pliocene and Pleistocene ridges, Holocene sediment buildups generate coastlines and marine buildups which define the coastal complex. Along the northern shore of Florida Bay, transgressive to regressive coastal storm levees of carbonate mud form the shoreline. Broad progradational peat and coastal sand and mud accumulations form a coastal mangrove forest and transitional marsh complex along the western shoreline (Wanless *et al.*, 1995). The study area is characterized by elevations that are generally less than 0.3 m above mean sea level (MSL) (Spackman *et al.*, 1966). In the area south of Lake Okeechobee, elevations are as much as 10 m above MSL and gently slope to the south (Spackman *et al.*, 1966). Changes in topography, although subtle, are significant in that natural highs and lows strongly influence the depth of the water table, thickness of Holocene sediment, and the surface flow of water in a given area (Riegel, 1965). The primary inputs of surface water to the study area are overflow from Lake Okeechobee and local rainfall. In the approximately 4000 sq. miles (6,400 km²) of the Everglades depression, water moves as sheet flow (Spackman *et al.*, 1966), although historically, human channelization of flow has disrupted the natural flow system to varying degrees (McIvor *et al.*, 1994; Smith *et al.*, 1989).

VEGETATION COMMUNITIES

South Florida has a very distinct zonation of vegetation that is strongly related to salinity, hydroperiod, elevation, and substrate (Riegel, 1965; Text-fig. 2). The boundaries between zones are usually abrupt (Cohen, 1968) except in estuaries. Here, transitional com-



nities, as well as upland vegetation. The spatial distribution of communities is shown in Text-figure 2.

Coastal Mangrove Fringe (Mangrove Swamp)

Mangrove forests of varying heights dominate the coastal margin of the study area. These forests are essentially a continuous cover of woody vegetation that is tolerant of high salinity and changes in hydroperiod related to inundation by tides. The forests produce root peat deposits that may develop into peat islands or shore-parallel wedges that are dissected by river channels draining the Everglades Basin. The interior of these islands is commonly higher in elevation and develops into a saltwater marsh or coastal prairie supporting less water-tolerant woody species (Bancroft *et al.*, 1994). *Rhizophora* (red mangrove), *Avicennia* (black mangrove) and *Laguncularia* (white mangrove) dominate the mangrove forest. Light gaps permit the growth of *Batis* (saltwort). The coastal levees of the mangrove swamp are capable of supporting a variety of upland vegetation. Prior to devastation by Hurricane Donna (1960), *Avicennia* forests were prevalent in the areas around Flamingo and the lower Shark River Slough (Craighead and Gilbert, 1962). These regrowth forests are now primarily composed of *Rhizophora*.

Brackish and Headwater Marsh

A brackish zone develops parallel to the coast where fresh water runoff from the mainland mixes with marine waters of the Gulf and Florida Bay. The location and extent of this brackish transitional zone varies with tidal influences and seasonal changes in the amount of freshwater input. Physiographically, the vegetation communities of southwestern Florida are parallel to the coast consistent with the salinity gradient (Text-fig. 2). Two brackish transitional zones can be distinguished. One occurs parallel to the coast and away from the major freshwater outflow of the Shark River Slough. This brackish, transitional marsh is dominated by *Rhizophora*, *Avicennia*, *Laguncularia*, *Typha* (cattail), *Spartina* (eelgrass), and *Cladium* (sawgrass). A second transitional zone, the headwater marsh, occurs adjacent to the outflow of the Shark River Slough in the zone of fluctuating freshwater and marine influences. This area is dominated by a network of river channels of the Shark River Slough/Little Shark River complex. Vegetation in the area is a mixture of *Rhizophora*, *Avicennia*, *Laguncularia*, *Conocarpus* (buttonwood), *Spartina*, *Scirpus* (bulrush), *Typha*, *Cladium*, and *Myrica* (wax myrtle) (Bancroft *et al.*, 1994).

Freshwater Marsh and Slough Environments

Inland from the coastal bays, waters become fresher and mangrove communities diminish. These more in-

land vegetation communities can once again be divided based on species tolerance to fluctuations in salinity and hydroperiod. The freshwater areas can be divided into freshwater marsh—slough (the primary vegetation-choked waterways developed in the Everglades Basin) and freshwater marsh with hammocks (tree islands). Sloughs and marshes are prairies of grasses and sedges that comprise the largest percentage of the freshwater area. *Cladium*, *Eleocharis* (spikerush), *Panicum* (maiden cane), *Muhlenbergia* (Muhly grass) and *Rhynchospora* (beakrush) are the primary sedges and grasses. In the wetter slough areas, emergent aquatics also are abundant including *Sagittaria* (arrowhead), *Nymphaea* (water lily) and *Utricularia* (bladderwort) (Gunderson, 1994). In the freshwater marsh with hammocks, tree islands or hammocks commonly develop. Communities can be divided into Bayheads, Willow Heads, and Cypress Forests (Gunderson, 1994) and include a diverse mixture of *Persea* (red bay), *Ilex* (dahoon holly), *Anona* (pond apple), *Myrica* (wax myrtle), *Salix* (willow), *Chrysobalanus* (cocoplum), and *Taxodium* (bald cypress), in addition to numerous other species that occur in low abundances.

Upland Complex

Toward the rim of the Everglades depression are bedrock highs on which pinelands and hardwood forests dominate. Pine uplands are found along the eastern margin of the Everglades on the Atlantic Coastal Ridge and extend into Everglades National Park along limestone ridges (Gunderson, 1994). Rockland pine forests are dominated by monotypic stands of *Pinus elliotti* (slash pine). Additionally, an assortment of palms, including *Sabal* (cabbage palm) and *Serenoa* (saw palmetto) are common.

Tropical hardwood hammocks occur on rock substrates most commonly in the southern Everglades. *Quercus* (live oak), *Lysiloma* (wild tamarind), *Bursera* (gumbo-limbo), and *Swietenia* (mahogany) are common hammock species. In many areas, dense hammocks primarily comprised of the bald cypress *Taxodium distichum* have developed. Orchids, bromeliads, and ferns are also present, but are not abundant.

PART A: CHARACTERIZATION OF MODERN POLLEN ZONES IN SOUTH FLORIDA FROM SURFACE POLLEN SAMPLES

Data for the first part of this study, the delineation of contemporary pollen zones in South Florida, was obtained from Appendix II of Riegel (1965) who completed the first extensive palynological analysis of Everglades National Park. His objectives were effectively the same as ours: to determine the relationship between pollen from surface sediments and the local

plant communities of the same area, and to characterize late Holocene ecological changes by comparing pollen preserved in sedimentary sequences with those found in the surface sediments. However, Riegel's (1965) methods differ from ours. His data were presented in a series of tables and abundance histograms designed to display the distribution of pollen and spores both at the surface and in sediment cores. His analysis focused on the means and variances of indicator species and their abundance. Results indicated, as expected, that the content of pollen assemblages was not directly proportional to the species composition of the parent plant communities; however, depositional environments could be recognized by pollen types that were transport-limited, and from vegetation communities restricted by salinity, hydroperiod, and elevation.

The original data set is a matrix consisting of the percent frequency of 92 taxonomic and morphologic pollen and spore categories collected from 102 sample sites, representing six of the ten major vegetation communities presented in that report (Text-fig. 2). Riegel (1965) followed standard preparation procedures and counting was conducted on at least three slides per sample. For each site, Riegel (1965) attempted to count a minimum of 150 grains. Pollen was not abundant in some samples and, on occasion, counting was stopped after reaching a minimum of 100 grains. Several of Riegel's (1965) samples taken from detrital sediments were removed from the data set for this study in order to restrict the analysis to samples from *in situ* depositional localities. The 92 taxonomic and morphologic categories in the original data set were reduced to 47 categories that could be associated with known parent plants present in surface vegetation communities. Twelve samples were collected from the Joe River area along a transect less than 300 m long extending from the mangrove fringe into the transitional marsh of northwest Cape Sable. This represents a much greater density of sites than for any of the other environments sampled by Riegel (1965) in South Florida. In order to avoid biasing the present data set, only one sample, JR-1, was selected from the Joe River transect. The final data set consisted of 47 taxonomic and morphologic pollen and spore categories and 86 surface sampling sites (Text-fig. 2).

Statistical Methods

Two multivariate statistical methods, cluster analysis and discriminant analysis, were applied to the data. Cluster analysis is a technique that classifies samples or taxa into relatively homogenous groups based on inter-object similarities (Davis, 1986; Kachigan, 1991). Two separate cluster analyses were used; one for as-

sociations of pollen and spores (taxonomic) and the other for surface sample associations (environmental). A hierarchical clustering technique, using Ward's sum of squares linkage method (Ward, 1963) and Chi-squared distances, were used in each analysis. Ward's method, which sums the squared Euclidean distances between each sample and the cluster means, is the preferred linkage technique because at each stage in the cluster analysis two samples or clusters are merged in a manner that arrives at the lowest within-group sum of square totals (Davis, 1986; Kachigan, 1991). All statistical calculations presented in this study were performed using SYSTAT version 6.0 (SPSS Inc., 1996).

Cluster analysis produces a dendrogram with objects (*i.e.*, samples or taxa) on the vertical axis and a distance measurement that defines where clusters join on the horizontal axis. Any vertical slice through the dendrogram should produce distinct groups that have maximized inter-object similarities. The statistical validity of the groups obtained from cluster analysis of surface samples was tested using discriminant analysis. Discriminant analysis evaluates the distinctiveness of predefined groups by calculating discriminant functions representing a linear combination of measured variables (Davis, 1986). Likewise, discriminant function scores are calculated for each sample by transforming the original set of measurements into a single value on each function. The mean, variance, and confidence intervals for function scores were calculated for each group and used to evaluate the distinctiveness of cluster-generated groupings. Function coefficients are calculated for each variable in the data set (*i.e.*, taxa) permitting the identification of variables that most strongly contribute to group separation along each function.

Results for Surface Samples

Cluster Analysis of Taxa

The dendrogram from cluster analysis of the 47 pollen and spore categories can be divided into four cluster groups (Text-fig. 3). Cluster A is further divided into three sub-clusters. Cluster A1 contains *Rhus*, *Sphagnum*, *Caryophyllaceae*, *Fraxinus*, *Eugenia*, *Carya*, *Rhabdadenia*, *Ericaceae*, *Hamelia*, *Ulmus*, *Pteris*, *Rapanea*, cf. *Thomsonopolis*, *Nyssa*, *Myrtaceae*, *Nuphar*, *Ficus*, *Polygona*, *Morus*, and *Alnus*. Cluster A2 contains *Sapotaceae*, *Vitis*, *Ilex*, *Anacardium*, and *Osmunda*. Cluster A3 contains *Compositae*, *Quercus*, *Typha*, *Gramineae*, *Salix*, *Cephalanthus*, *Polypodium*, and *Taxodium*. Cluster B contains chenopods. Cluster C contains triporates, *Cyperaceae*, *Sagittaria*, *Utricularia*, *Umbelliferae*, cf. *Ovoidites*, *Nymphaea*, and *Pi-*

Table 1.—Southwestern Florida surface pollen and spore data arranged by environmental cluster groupings. Data from Riegel (1965) are percentage abundance of the original sample. All samples do not total 100% because of the exclusion of taxonomic/morphologic categories that could not be associated with known parent vegetation. Average (Avg.), standard deviation (st. dev.), and 95% confidence intervals (CI) are presented for each cluster group.

Site	Cluster	<i>Rhizophora</i>	<i>Avicennia</i>	<i>Lagun- cularia</i>	<i>Conocarpus</i>	<i>Batis</i>	Cheno- pods	Gramineae	Cyperaceae
Mangrove Swamp (N = 10)									
62-01	1	58.7	7.3	0.7	7.3	0.0	7.4	0.0	0.7
62-06	1	55.7	5.4	0.0	4.2	1.8	7.8	1.2	0.6
62-08	1	64.0	3.1	1.2	3.1	3.1	6.1	0.0	0.0
62-11	1	63.5	0.0	0.6	1.8	2.4	6.0	0.0	0.0
62-12	1	66.1	0.0	2.5	0.0	0.6	4.3	0.6	0.6
62-15	1	58.7	0.6	1.2	4.3	0.6	11.8	0.6	1.2
62-17	1	61.0	1.8	1.2	0.6	0.6	7.9	0.0	0.6
62-20	1	56.0	3.3	2.2	2.2	1.6	4.9	0.0	1.1
62-21	1	43.7	7.6	2.5	6.3	2.5	8.3	0.0	1.3
62-22	1	46.9	1.1	1.7	0.6	1.7	2.8	0.6	1.7
	Avg.	57.4	3.0	1.4	3.0	1.5	6.7	0.3	0.8
	Stdev.	7.3	2.9	0.8	2.5	1.0	2.5	0.4	0.5
	CI	4.5	1.8	0.5	1.5	0.6	1.6	0.3	0.3
Mangrove Swamp (N = 15)									
62-02	2	16.6	9.6	0.0	5.6	29.6	25.8	1.0	0.0
62-03	2	29.4	5.2	0.5	5.7	10.8	28.4	2.1	0.0
62-05	2	27.2	9.5	1.2	4.7	7.1	21.9	1.2	0.0
62-07	2	34.3	1.2	1.2	5.4	4.2	18.1	2.4	0.0
62-09	2	38.9	5.1	0.6	5.7	3.8	10.2	1.3	1.3
62-10	2	43.5	2.0	1.3	2.0	0.0	11.7	1.3	1.3
62-13	2	37.3	3.3	1.3	3.9	1.3	13.1	0.7	0.0
62-14	2	39.6	4.5	1.1	2.3	1.7	10.8	1.1	1.1
62-18	2	49.0	1.9	3.9	3.2	2.6	8.5	0.0	0.7
62-19	2	25.1	6.7	1.7	1.7	0.0	10.7	1.1	1.1
64-11	2	11.7	0.6	3.7	1.8	0.0	12.2	1.9	4.3
64-21	2	19.8	1.7	16.4	11.8	0.0	5.9	0.9	0.0
SR-01	2	37.5	1.3	1.3	3.3	3.9	8.5	0.0	0.7
SR-02	2	32.3	6.2	1.2	2.3	3.5	15.2	0.0	0.0
59-T1	2	30.7	6.1	8.9	2.4	0.0	9.2	1.2	0.0
	Avg.	31.5	4.3	3.0	4.1	4.6	14.0	1.0	0.7
	Stdev.	10.2	2.9	4.3	2.6	7.6	6.7	0.7	1.1
	CI	5.2	1.5	2.2	1.3	3.8	3.4	0.4	0.6
Mangrove Swamp (N = 11)									
SR-03	3	44.4	2.7	0.9	14.2	1.3	11.1	0.0	0.0
SR-04	3	40.9	3.2	1.9	11.1	1.9	6.7	0.0	0.9
SR-05	3	32.6	0.0	1.1	4.9	0.0	23.9	0.0	0.5
SR-06	3	33.5	1.1	0.5	6.5	0.0	17.9	0.3	1.4
SR-07	3	32.7	0.3	0.6	8.0	0.3	9.5	0.0	0.6
SR-09	3	52.4	2.9	1.3	6.8	0.3	6.5	0.0	0.7
SR-10	3	36.2	0.9	1.9	5.7	0.0	18.1	0.0	0.0
SR-13	3	13.6	0.0	1.1	8.2	1.1	35.3	0.0	0.5
SR-14	3	13.5	2.4	0.6	12.9	0.0	21.2	0.6	2.4
SR-15	3	36.9	0.0	1.9	2.5	0.0	18.1	0.6	0.6
SR-16	3	29.1	0.0	0.7	11.3	0.0	8.6	0.7	2.0
	Avg.	33.3	1.2	1.1	8.4	0.4	16.1	0.2	0.9
	Stdev.	11.7	1.3	0.5	3.6	0.7	8.8	0.3	0.8
	CI	6.9	0.8	0.3	2.1	0.4	5.2	0.2	0.5
Freshwater Marsh (N = 9)									
62-34	4	1.2	0.0	0.6	1.2	0.6	2.9	7.5	6.4
64-04	4	0.5	0.0	0.0	0.5	0.0	2.8	4.2	2.8
64-07	4	0.0	0.0	0.0	0.4	0.0	4.3	2.2	3.0
64-E7SG	4	0.0	0.0	0.0	0.0	0.0	13.9	1.2	5.2
64-09	4	1.2	0.0	0.0	0.0	0.0	8.8	2.3	12.3
64-15	4	0.0	0.0	0.0	0.5	0.0	16.9	1.4	5.5
64-16SG	4	0.0	0.0	0.0	0.5	0.0	7.4	2.1	6.4
SLTR-03	4	0.0	0.0	0.0	0.0	0.0	17.3	1.4	7.3
SLTR-04	4	0.0	0.0	0.0	1.0	0.0	13.1	0.0	4.7
	Avg.	0.3	0.0	0.1	0.5	0.1	9.7	2.5	6.0
	Stdev.	0.5	0.0	0.2	0.4	0.2	5.8	2.2	2.8
	CI	0.3	0.0	0.1	0.3	0.1	3.8	1.4	1.8

Table 1.—Extended.

<i>Typha</i>	<i>Nym- phaea</i>	<i>Sagit- taria</i>	<i>Umbel- liferae</i>	<i>Utricu- laria</i>	<i>Com- positae</i>	<i>Poly- gona</i>	Caryo- phylla- ceae	<i>Ilex</i>	<i>Salix</i>	<i>Morus</i>	<i>Ficus</i>	Trip- orates	<i>Eu- genia</i>	<i>Cephal- anthus</i>	<i>Frax- inus</i>	Sapot- aceae
0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.6	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.6	0.0	3.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.6	0.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.6	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.6	0.0	0.0	0.0	0.0	6.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.1	0.1	0.0	0.1	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3	0.3	0.0	0.2	0.0	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.2	0.2		0.1		0.8											
0.2	0.2	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.6	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.7	0.7	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
0.7	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.6	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
0.7	0.7	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.6	0.0	0.0	0.0	0.0	9.6	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0
0.0	0.0	0.0	0.6	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	3.1	0.0	0.5	0.5	0.0
0.0	1.3	0.0	0.4	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.4	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.7	0.0	0.7	0.0	0.0	2.0	0.0	0.0	0.0	0.0
0.0	0.4	0.4	0.9	0.0	2.4	0.0	0.4	0.0	0.0	0.0	0.0	3.9	0.0	0.0	0.0	0.0
0.0	1.2	0.0	0.6	0.0	3.0	0.0	0.0	0.6	0.0	0.6	0.6	1.9	0.0	0.0	0.0	0.6
0.2	0.3	0.1	0.2	0.0	1.9	0.0	0.1	0.0	0.0	0.0	0.0	0.9	0.0	0.0	0.1	0.1
0.3	0.5	0.2	0.3	0.0	2.3	0.0	0.2	0.2	0.2	0.2	0.2	1.3	0.1	0.1	0.2	0.2
0.1	0.2	0.1	0.2		1.2		0.1	0.1	0.1	0.1	0.1	0.7	0.1	0.1	0.1	0.1
0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	4.8	0.0	0.0	0.0	0.0
0.0	0.3	0.3	0.3	0.0	1.8	0.0	0.0	0.3	0.0	0.0	0.0	4.4	0.0	0.0	0.0	0.3
0.0	0.5	0.5	0.0	0.0	4.2	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	1.1
0.3	0.8	1.4	0.3	0.3	3.0	0.0	0.0	0.0	0.0	0.0	0.3	5.4	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.3	0.0	0.6	0.0	0.0	0.0	0.3	0.0	0.3	5.4	0.0	0.0	0.0	0.0
0.0	0.0	0.7	0.3	0.0	3.3	0.0	0.0	0.0	0.0	0.0	0.0	5.5	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0
0.0	1.1	0.0	0.0	0.5	2.0	0.0	0.0	0.0	0.5	0.0	0.0	4.3	0.0	0.0	0.0	0.0
0.0	0.6	1.8	0.0	0.0	3.0	0.6	0.0	0.6	0.0	0.0	0.0	5.9	0.0	0.0	0.0	0.0
0.0	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.6	8.1	0.0	0.0	0.0	0.0
0.7	0.0	0.7	0.0	0.0	1.4	0.0	0.0	0.7	0.0	0.0	0.0	13.9	0.0	0.0	0.0	0.0
0.1	0.4	0.5	0.1	0.1	2.2	0.1	0.0	0.1	0.1	0.0	0.1	5.9	0.0	0.0	0.0	0.1
0.2	0.4	0.6	0.2	0.2	1.3	0.2	0.0	0.3	0.2	0.0	0.2	3.0	0.0	0.0	0.0	0.3
0.1	0.2	0.4	0.1	0.1	0.8	0.1		0.2	0.1		0.1	1.8				0.2
0.6	0.0	11.5	0.6	0.0	4.0	0.6	0.0	0.6	0.0	2.3	0.0	17.9	0.0	0.0	0.0	1.7
6.1	0.5	10.7	0.5	0.0	3.2	0.0	0.0	0.0	0.9	0.0	0.0	9.9	0.0	0.0	0.5	0.0
0.9	0.0	3.9	1.3	0.9	2.5	0.0	0.0	0.0	0.4	0.0	0.0	8.7	0.4	0.4	0.0	0.0
0.0	1.2	1.2	1.7	1.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	12.1	0.0	1.7	0.0	0.0
0.0	1.2	9.3	1.2	1.8	2.9	0.0	0.0	1.2	1.2	0.0	0.0	9.4	0.0	1.2	0.0	0.0
0.0	1.8	0.9	0.9	0.9	2.3	0.0	0.0	0.5	0.5	0.0	0.0	6.9	0.0	0.9	0.0	0.0
0.5	6.9	3.7	2.1	0.5	2.7	0.0	0.0	0.5	0.0	0.0	0.5	21.2	0.0	0.0	0.0	0.0
0.0	8.2	1.4	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.5	0.0	7.7	0.0	0.5	0.0	0.0
0.0	8.9	1.0	0.0	1.0	0.5	0.0	0.0	0.0	1.0	0.0	0.0	11.5	0.0	0.5	0.0	0.0
0.9	3.2	4.8	0.9	0.7	2.2	0.1	0.0	0.3	0.4	0.3	0.1	11.7	0.0	0.6	0.1	0.2
2.0	3.7	4.4	0.7	0.6	1.2	0.2	0.0	0.4	0.5	0.8	0.2	4.8	0.1	0.6	0.2	0.6
1.3	2.4	2.9	0.5	0.4	0.8	0.1		0.3	0.3	0.5	0.1	3.1	0.1	0.4	0.1	0.4

Table 1.—Continued.

Site	Cluster	<i>Quercus</i>	<i>Anacardium</i>	<i>Alnus</i>	<i>Carya</i>	<i>Nyssa</i>	<i>Taxodium</i>	cf. <i>Ovoidites</i>	<i>Vitis</i>	<i>Rapanea</i>
Mangrove Swamp (N = 10)										
62-01	1	0.0	1.3	0.0	0.0	0.0	0.7	0.0	0.0	0.0
62-06	1	1.2	5.4	0.0	0.0	0.0	1.2	0.0	0.0	0.0
62-08	1	1.2	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0
62-11	1	0.0	2.4	0.0	0.0	0.0	3.0	0.0	0.6	0.0
62-12	1	0.0	1.2	0.0	0.0	0.0	2.5	0.0	0.0	0.0
62-15	1	1.2	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
62-17	1	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
62-20	1	0.0	1.2	0.0	0.0	0.0	1.6	0.0	0.0	0.0
62-21	1	1.9	0.0	0.0	1.3	0.0	3.2	0.0	0.6	0.0
62-22	1	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0
	Avg.	0.6	1.2	0.0	0.1	0.0	1.6	0.0	0.1	0.0
	Stdev.	0.7	1.7	0.0	0.4	0.0	1.1	0.0	0.3	0.0
	CI	0.5	1.0		0.3		0.7		0.2	
Mangrove Swamp (N = 15)										
62-02	2	0.5	1.2	0.0	0.0	0.0	0.2	0.0	0.0	0.0
62-03	2	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0
62-05	2	3.0	1.8	0.0	0.0	0.0	0.5	0.0	0.0	0.0
62-07	2	0.0	0.0	0.0	0.0	0.0	2.4	0.0	0.0	0.0
62-09	2	1.3	1.3	0.6	0.0	0.0	1.3	0.0	0.0	0.0
62-10	2	1.4	0.7	0.7	0.1	0.0	1.3	0.0	0.0	0.0
62-13	2	4.0	2.6	0.7	0.0	0.0	0.0	0.0	0.7	0.0
62-14	2	2.3	1.1	0.0	0.0	0.0	1.7	0.0	0.0	0.0
62-18	2	3.9	0.0	0.0	0.0	0.0	4.5	0.0	0.0	0.0
62-19	2	4.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
64-11	2	2.5	0.6	0.0	0.0	0.0	2.5	0.6	0.0	0.0
64-21	2	2.1	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0
SR-01	2	1.3	0.0	0.0	0.0	0.0	3.3	0.0	0.0	0.0
SR-02	2	4.3	0.4	0.8	0.0	0.0	0.4	0.4	0.0	0.0
59-T1	2	3.3	1.2	0.0	0.0	0.0	2.5	0.0	0.0	0.0
	Avg.	2.2	0.7	0.2	0.0	0.0	1.5	0.1	0.0	0.0
	Stdev.	1.7	0.8	0.3	0.0	0.0	1.4	0.3	0.2	0.0
	CI	0.7	0.4	0.2	0.0		0.7	0.1	0.1	
Mangrove Swamp (N = 11)										
SR-03	3	0.9	0.0	0.0	0.0	0.0	0.0	0.9	0.0	0.0
SR-04	3	3.2	0.0	0.0	0.0	0.0	0.3	0.6	0.0	0.0
SR-05	3	1.0	0.5	0.5	0.0	0.0	0.6	0.0	0.0	0.0
SR-06	3	2.5	0.3	0.0	0.0	0.0	0.6	1.7	0.0	0.0
SR-07	3	2.1	0.0	0.0	0.0	0.0	0.9	1.2	0.0	0.0
SR-09	3	0.3	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0
SR-10	3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR-13	3	2.7	0.0	0.0	0.0	0.0	1.1	0.0	0.5	0.0
SR-14	3	1.2	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0
SR-15	3	0.6	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0
SR-16	3	0.7	0.0	0.7	0.0	0.0	1.3	0.7	0.0	0.0
	Avg.	1.4	0.1	0.1	0.0	0.0	0.7	0.6	0.0	0.0
	Stdev.	1.1	0.2	0.2	0.0	0.0	0.5	0.6	0.2	0.0
	CI	0.6	0.1	0.1			0.3	0.4	0.1	
Freshwater Marsh (N = 9)										
62-34	4	1.2	0.6	0.6	0.0	0.0	1.2	2.9	1.7	0.0
64-04	4	3.2	0.0	0.0	0.0	0.0	3.8	15.0	0.0	0.0
64-07	4	1.3	0.4	0.4	0.0	0.0	1.7	10.3	0.0	0.0
64-E7SG	4	1.2	0.0	1.2	0.0	0.0	2.3	8.7	0.0	0.0
64-09	4	2.4	0.6	0.0	0.0	0.0	5.3	15.8	1.2	1.2
64-15	4	1.0	0.0	0.0	0.0	0.0	1.4	12.8	0.0	0.0
64-16SG	4	0.5	0.0	0.5	0.0	0.0	0.5	11.2	0.0	0.0
SLTR-03	4	0.9	0.9	0.0	0.0	0.0	1.8	8.2	0.0	0.0
SLTR-04	4	1.0	0.0	0.0	0.0	0.0	3.1	5.8	0.0	0.0
	Avg.	1.4	0.3	0.3	0.0	0.0	2.3	10.1	0.3	0.1
	Stdev.	0.8	0.4	0.4	0.0	0.0	1.5	4.2	0.7	0.4
	CI	0.6	0.2	0.3			1.0	2.7	0.4	0.3

Table 1.—Continued Extended.

<i>Hame- lia</i>	<i>Rhus</i>	<i>Myrt- aceae</i>	<i>Osmunda</i>	<i>Poly- podium</i>	<i>Eric- aceae</i>	<i>Sphag- num</i>	<i>Ulmus</i>	cf. <i>Thom- sono- pollis</i>	<i>Nuphar</i>	<i>Rhab- daden- ia</i>	<i>Pteris</i>	<i>Liquid- amber</i>	<i>Pinus</i>	Other	Grains count- ed	Grains used for stats
0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	10.1	150	133
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.6	5.5	167	156
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.3	8.7	164	148
0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.2	8.5	167	151
0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	7.1	162	149
0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	4.7	162	153
0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.9	12.6	164	142
0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.8	4.6	184	174
0.0	0.0	0.0	0.6	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	10.9	158	139
0.0	0.0	0.0	0.0	1.1	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	20.7	11.7	179	156
0.0	0.1	0.0	0.1	0.7	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	8.7	9.4		
0.0	0.2	0.0	0.2	0.6	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	5.7	69.0		
	0.1		0.1	0.3		0.1							3.5	80.8		
0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.3	0.5	591	576
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8	4.5	194	181
0.0	0.0	0.0	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.9	9.2	n/a	n/a
0.0	0.0	0.0	1.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	16.2	166	136
0.0	0.0	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.9	15.2	157	130
0.0	0.0	0.0	0.7	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.2	7.6	154	139
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.4	10.7	153	134
0.0	0.0	0.0	1.7	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.3	8.5	177	158
0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.6	3.4	155	147
0.0	1.1	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	27.4	6.6	179	164
0.0	0.0	0.0	3.1	3.1	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	6.8	36.1	n/a	n/a
0.0	0.0	0.0	18.1	0.9	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.4	4.1	238	223
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.8	15.1	152	126
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.2	7.4	257	233
0.0	0.0	0.0	1.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.3	5.1	163	151
0.0	0.1	0.0	1.8	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.8	12.1		
0.0	0.3	0.0	4.6	1.0	0.1	0.2	0.0	0.0	0.2	0.0	0.0	0.0	5.6	41.0		
	0.1		2.3	0.5	0.1	0.1			0.1				2.8	70.1		
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.0	7.0	225	203
0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.4	6.9	315	284
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	8.8	184	162
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	6.4	352	319
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.6	25.3	336	241
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.4	4.3	307	285
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.6	19.9	105	81
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.3	7.2	184	165
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.8	19.7	170	131
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.3	18.3	160	126
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.3	14.5	151	125
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.2			
0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.1			
	0.1												1.8			
0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.9	25.9	173	121
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.4	30.9	213	139
0.0	0.0	0.0	0.0	3.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	47.8	49.2	232	109
0.0	0.0	0.0	3.5	3.5	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	33.5	35.0	173	106
0.0	0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	17.0	13.1	171	142
0.0	0.0	0.0	0.9	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.4	38.2	219	127
0.0	0.0	0.0	1.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.9	25.2	218	154
0.0	0.0	0.0	6.3	2.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.2	30.0	220	145
0.0	0.0	0.0	2.6	3.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.5	36.7	213	126
0.0	0.0	0.0	1.6	2.3	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	28.3			
0.0	0.0	0.0	2.2	1.2	0.0	0.0	0.2	0.2	0.0	0.0	0.0	0.0	10.1			
			1.4	0.8			0.1	0.1					6.6			

Table 1.—Continued.

Site	Cluster	<i>Rhizophora</i>	<i>Avicennia</i>	<i>Lagun- cularia</i>	<i>Conocarpus</i>	<i>Batis</i>	Cheno- pods	Gramineae	Cyperaceae
Freshwater Marsh (N = 8)									
62-23	5	0.6	0.0	0.0	0.0	0.0	34.8	0.0	5.6
64-E7E	5	0.0	0.0	0.0	0.0	0.0	37.2	1.0	1.3
64-10	5	0.0	0.0	0.0	0.0	0.0	33.8	0.0	3.6
64-16E	5	0.0	0.0	0.0	0.6	0.0	27.7	0.0	3.2
64-16ASG	5	0.0	0.0	0.0	0.0	0.0	47.2	0.5	1.8
64-16AE	5	1.2	0.0	0.0	0.0	0.0	31.1	1.2	1.2
SLTR-01	5	0.4	0.0	0.0	0.0	0.0	22.9	3.1	1.9
SLTR-02	5	0.5	0.0	0.0	0.0	0.0	27.1	0.5	3.2
	Avg.	0.3	0.0	0.0	0.1	0.0	32.7	0.8	2.7
	Stdev.	0.4	0.0	0.0	0.2	0.0	7.5	1.0	1.5
	CI	0.3			0.1		5.2	0.7	1.0
Headwater Marsh (N = 5)									
64-33	6	0.0	3.4	0.0	0.6	16.2	62.1	0.0	0.6
SR-25	6	0.5	0.0	0.3	0.0	0.0	80.5	0.3	2.1
SR-26	6	0.9	0.0	0.0	0.0	0.0	78.4	0.0	1.3
SR-28	6	0.4	0.0	0.4	0.0	0.0	70.6	0.0	0.4
SR-29	6	1.3	0.3	0.0	0.0	0.0	89.9	0.0	0.3
	Avg.	0.6	0.7	0.1	0.1	3.2	76.3	0.1	0.9
	Stdev.	0.5	1.5	0.2	0.3	7.2	10.5	0.1	0.8
	CI	0.4	1.3	0.2	0.2	6.4	9.2	0.1	0.7
Headwater Marsh (N = 10)									
62-24	7	2.3	0.0	0.0	0.0	0.0	37.3	2.3	1.7
SR-17	7	18.2	1.1	0.0	1.7	0.0	22.7	0.6	1.7
SR-18	7	24.4	0.0	0.0	3.6	0.6	31.5	0.0	4.2
SR-19	7	11.0	0.5	1.0	4.0	0.0	33.0	0.0	3.0
SR-20	7	20.1	0.7	0.0	2.0	0.0	22.8	0.0	0.7
SR-21	7	28.7	0.5	0.5	1.1	0.0	23.2	0.0	1.1
SR-22	7	8.9	0.0	0.0	0.0	0.0	47.3	0.0	0.8
SR-23	7	15.4	1.1	0.0	0.0	0.5	44.0	0.0	2.2
SR-24	7	6.8	0.9	0.0	0.9	0.0	47.7	0.0	1.4
SR30	7	25.6	1.8	0.6	1.2	0.0	14.9	0.0	1.8
	Avg.	16.1	0.7	0.2	1.5	0.1	32.4	0.3	1.9
	Stdev.	8.8	0.6	0.4	1.4	0.2	11.5	0.7	1.1
	CI	5.4	0.4	0.2	0.9	0.1	7.1	0.5	0.7
Brackish Marsh (N = 9)									
62-25	8	7.9	0.0	0.0	3.4	0.0	11.9	0.0	4.5
62-30	8	7.0	0.0	0.0	10.2	0.6	8.3	1.3	8.9
64-18	8	9.5	0.0	0.0	1.1	1.6	10.6	2.0	16.4
64-22	8	2.3	0.0	0.6	1.1	1.7	5.6	0.5	17.0
HR-01	8	12.2	0.0	0.0	19.1	0.9	7.3	1.9	0.9
HR-02	8	16.0	0.6	1.9	13.5	0.6	7.0	1.9	1.9
JR-01	8	3.7	0.0	0.7	4.1	0.0	4.8	0.0	3.0
TB-01	8	16.9	0.0	0.0	4.5	1.1	19.1	0.6	11.2
TB-02	8	16.4	0.0	0.0	3.0	0.0	9.7	1.7	8.5
	Avg.	10.2	0.1	0.4	6.7	0.7	9.4	4.2	8.0
	Stdev.	5.5	0.2	0.6	6.2	0.7	4.3	9.5	6.0
	CI	3.6	0.1	0.4	4.1	0.4	2.8	6.2	3.9
Brackish Marsh (N = 5)									
62-26	9	1.3	0.0	0.0	1.3	0.0	6.3	1.3	2.5
62-33b	9	0.0	0.0	0.0	0.9	0.9	0.9	0.0	2.8
62-35	9	0.0	0.0	0.0	0.5	0.0	0.5	0.0	1.6
64-09H	9	0.0	0.0	0.0	0.0	0.0	15.1	0.6	3.1
64-14	9	1.2	0.0	0.0	0.0	1.2	3.6	2.4	3.6
	Avg.	0.5	0.0	0.0	0.5	0.4	5.3	0.9	2.7
	Stdev.	0.7	0.0	0.0	0.6	0.6	6.0	1.0	0.7
	CI	0.6			0.5	0.5	5.2	0.9	0.7
Upland (N = 4)									
62-27	10	0.0	0.0	0.0	0.0	0.0	1.1	0.6	1.1
62-28	10	0.6	0.0	0.0	0.6	0.0	1.2	3.8	3.8
62-29	10	0.6	0.0	0.0	0.0	0.0	1.7	0.0	0.0
EE-11	10	0.0	0.0	0.0	0.0	0.0	0.6	0.6	4.1
	Avg.	0.3	0.0	0.0	0.2	0.0	1.2	1.3	2.3
	Stdev.	0.3	0.0	0.0	0.3	0.0	0.5	1.7	2.0
	CI	0.3			0.3		0.4	1.7	2.0

Table 1.—Continued Extended.

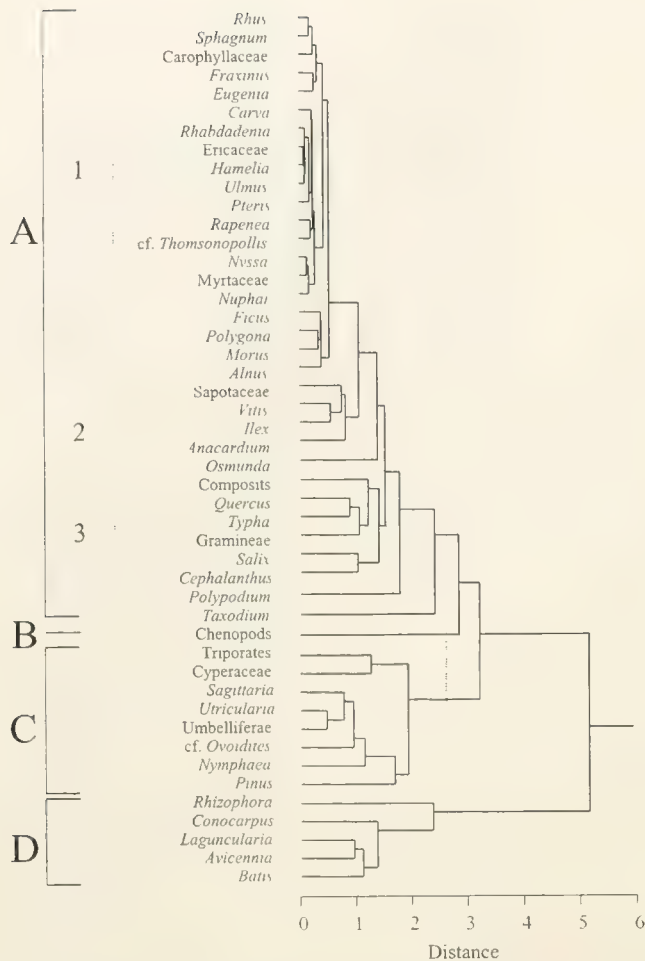
<i>Typha</i>	<i>Nym- phaea</i>	<i>Sagit- taria</i>	<i>Umbel- liferae</i>	<i>Utricu- laria</i>	<i>Com- positae</i>	<i>Poly- gona</i>	Caryo- phylla- ceae	<i>Ilex</i>	<i>Salix</i>	<i>Morus</i>	<i>Ficus</i>	<i>Trip- orates</i>	<i>Eu- genia</i>	<i>Cephal- anthus</i>	<i>Frax- inus</i>	<i>Sapot- aceae</i>
0.6	1.7	2.2	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	9.0	0.6	0.0	0.0	0.0
0.0	5.3	3.0	0.3	1.3	0.6	0.3	0.0	0.0	0.3	0.0	0.0	3.0	0.0	0.0	0.0	0.0
0.5	4.1	0.5	1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0	0.0	0.0
0.0	9.0	1.2	0.6	1.9	0.6	0.0	0.0	0.0	0.0	0.6	0.0	13.5	0.0	0.0	0.0	0.0
0.0	5.0	2.3	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	2.8	0.0	0.5	0.0	0.5
0.8	12.0	5.0	0.4	0.4	2.0	0.0	0.0	0.0	0.4	0.0	0.0	1.2	0.0	0.0	0.0	0.0
0.0	25.3	1.0	0.4	0.4	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	2.8
0.0	14.7	5.0	0.5	0.5	2.7	0.0	0.0	0.0	0.0	0.0	0.0	6.9	0.0	0.5	0.0	0.0
0.2	9.6	2.5	0.4	0.7	1.0	0.0	0.0	0.0	0.1	0.1	0.1	5.5	0.1	0.1	0.0	0.4
0.3	7.7	1.7	0.3	0.6	1.0	0.1	0.0	0.0	0.2	0.2	0.2	4.4	0.2	0.2	0.0	1.0
0.2	5.3	1.2	0.2	0.4	0.7	0.1			0.1	0.1	0.1	3.0	0.1	0.2		0.7
0.6	0.0	0.0	0.0	0.0	4.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.3	0.8	5.9	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	2.7	0.0	0.0	0.0	0.0
0.4	0.4	3.0	0.4	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.4	3.9	0.0	0.0	0.0	0.0
0.0	0.8	2.5	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.4	0.0	0.0
0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0	0.3	0.0	0.0
0.3	0.4	2.9	0.1	0.0	1.3	0.1	0.0	0.0	0.0	0.0	0.1	2.0	0.0	0.1	0.0	0.0
0.3	0.4	2.1	0.2	0.0	1.7	0.2	0.0	0.0	0.0	0.0	0.2	1.4	0.0	0.2	0.0	0.0
0.2	0.4	1.8	0.2		1.5	0.2					0.2	1.3		0.2		
2.3	1.7	1.0	1.3	0.0	10.3	0.0	0.0	0.3	1.7	0.0	0.0	11.7	0.0	1.0	0.0	0.0
0.0	2.3	1.7	0.0	0.0	2.4	0.0	0.0	1.1	0.6	0.0	0.0	20.4	0.0	0.0	0.0	0.0
0.0	0.0	1.2	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0	0.0	7.1	0.0	0.0	0.0	0.0
0.0	1.0	2.5	0.0	0.5	2.0	0.0	0.0	0.5	0.5	0.5	0.0	5.5	0.0	0.5	0.0	0.0
0.0	1.3	1.3	0.0	0.0	4.2	0.0	0.7	0.0	0.0	0.0	0.0	11.4	0.0	0.0	0.7	0.0
0.5	1.1	1.1	0.0	0.0	5.4	0.0	0.0	0.6	0.0	0.6	0.0	10.3	0.0	0.0	0.6	0.0
0.0	1.7	1.1	0.0	0.0	5.6	0.0	0.0	1.1	0.0	0.0	0.0	12.4	0.0	1.7	0.0	0.0
0.5	0.0	1.6	0.5	0.0	1.0	0.0	0.0	0.5	1.6	0.0	0.0	9.3	0.5	0.0	0.5	0.0
0.9	0.5	3.6	0.9	0.5	2.8	0.5	0.0	1.4	0.0	0.0	0.0	8.2	0.5	0.5	0.5	0.0
0.6	0.6	0.6	0.0	0.0	1.2	0.0	0.0	0.6	0.0	0.0	0.0	12.5	0.0	12.5	0.0	0.0
0.5	1.0	1.6	0.3	0.1	3.9	0.1	0.1	0.6	0.4	0.1	0.0	10.9	0.1	1.6	0.2	0.0
0.7	0.8	0.9	0.5	0.2	2.8	0.2	0.2	0.5	0.7	0.2	0.0	4.1	0.2	3.9	0.3	0.0
0.4	0.5	0.5	0.3	0.1	1.7	0.1	0.1	0.3	0.4	0.1		2.5	0.1	2.4	0.2	
1.1	0.0	0.0	0.0	0.0	1.8	0.0	0.0	2.8	0.0	0.0	1.1	17.6	0.0	1.1	0.0	0.6
5.1	0.0	0.0	0.0	0.0	6.4	0.0	0.0	0.0	0.6	0.0	0.6	14.6	0.0	0.0	0.0	0.0
1.6	0.0	0.0	0.0	0.0	4.2	0.0	0.0	0.5	0.5	1.1	0.5	11.1	0.0	0.0	0.0	0.0
0.0	0.6	0.6	0.6	0.0	2.8	0.0	0.0	1.1	0.6	0.0	0.0	20.9	0.0	0.0	0.4	0.0
0.0	0.0	0.9	0.0	0.0	4.4	0.0	0.0	0.9	0.9	0.0	0.9	19.1	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0	1.3	0.6	0.0	0.0	22.4	0.0	0.0	0.0	0.0
0.0	0.0	0.4	0.0	0.0	7.4	0.0	0.0	4.1	0.0	0.0	0.0	23.3	0.7	0.0	0.0	0.0
5.1	0.0	0.6	0.0	0.0	3.4	0.0	0.6	0.6	0.0	0.0	0.6	17.4	0.0	0.6	0.0	0.0
7.3	0.0	0.6	0.0	0.0	1.8	0.0	0.0	2.4	0.6	0.0	0.0	20.6	1.3	0.0	1.2	0.0
2.2	0.1	0.3	0.1	0.0	4.4	0.0	0.1	1.5	0.4	0.1	0.4	18.6	0.2	0.2	0.2	0.1
2.8	0.2	0.4	0.2	0.0	2.1	0.0	0.2	1.3	0.3	0.4	0.4	3.9	0.5	0.4	0.4	0.2
1.8	0.1	0.2	0.1		1.4		0.1	0.9	0.2	0.2	0.3	2.5	0.3	0.3	0.5	0.1
0.0	0.0	1.9	1.9	0.0	12.6	0.6	0.0	0.0	1.3	0.0	0.0	5.0	0.0	8.2	0.0	0.0
0.0	0.0	0.0	1.5	0.0	4.7	0.9	0.0	0.0	1.9	0.0	1.9	3.8	0.0	1.9	0.0	18.8
1.6	0.0	1.1	0.0	0.0	12.7	0.0	0.0	0.0	9.5	0.5	0.0	0.5	0.0	0.5	0.0	0.0
0.6	0.0	1.3	0.6	0.0	6.9	0.6	0.0	0.0	26.4	0.0	0.6	14.5	0.0	2.5	0.0	0.0
0.0	0.6	8.3	7.1	0.6	3.6	0.0	0.0	0.0	3.0	0.0	0.0	4.2	0.0	27.4	0.0	0.0
0.4	0.1	2.5	2.2	0.1	8.1	0.4	0.0	0.0	8.4	0.1	0.5	5.6	0.0	8.1	0.0	3.8
0.7	0.3	3.3	2.8	0.3	4.3	0.4	0.0	0.0	10.6	0.2	0.8	5.3	0.0	11.2	0.0	8.4
0.6	0.2	2.9	2.5	0.2	3.8	0.4			9.3	0.2	0.7	4.6		9.8		7.4
0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.6	0.6	0.0	0.0	0.6	0.0	2.8	0.0	0.0
0.6	0.0	0.6	0.0	0.0	4.6	0.6	0.0	0.0	5.7	0.0	0.0	1.3	0.0	0.0	0.0	0.0
0.6	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0	1.1	0.0	0.0	1.1	0.6	0.0	0.0	0.0
0.6	0.0	1.2	0.0	0.0	1.2	0.0	0.0	0.0	2.3	0.6	0.0	2.3	0.0	4.1	0.0	0.0
0.5	0.0	0.5	0.0	0.0	2.5	0.2	0.0	0.2	2.4	0.2	0.0	1.3	0.2	1.7	0.0	0.0
0.3	0.0	0.6	0.0	0.0	1.5	0.3	0.0	0.3	2.3	0.3	0.0	0.7	0.3	2.1	0.0	0.0
0.3		0.6			1.5	0.3		0.3	2.3	0.3		0.7	0.3	2.0		

Table 1.—Continued.

Site	Cluster	<i>Quercus</i>	<i>Anacardium</i>	<i>Alnus</i>	<i>Carya</i>	<i>Nyssa</i>	<i>Taxodium</i>	cf. <i>Ovoidites</i>	<i>Vitis</i>	<i>Rapanea</i>
Freshwater Marsh (N = 8)										
62-23	5	1.1	0.6	0.0	0.0	0.0	3.9	9.5	0.0	0.0
64-E7E	5	0.7	0.0	0.0	0.0	0.0	0.0	7.0	0.0	0.0
64-10	5	1.0	0.0	0.0	0.0	0.0	1.5	12.8	0.0	0.0
64-16E	5	0.0	0.6	0.0	0.0	0.0	3.9	8.4	0.0	0.0
64-16ASG	5	1.4	0.0	0.0	0.5	0.0	0.9	6.0	0.0	0.0
64-16AE	5	0.4	0.0	0.0	0.0	0.0	1.2	1.4	0.0	0.0
SLTR-01	5	0.0	0.0	0.0	0.0	0.0	2.3	9.6	0.0	0.0
SLTR-02	5	0.5	0.5	0.0	0.0	0.0	1.8	8.3	0.0	0.0
	Avg.	0.6	0.2	0.0	0.1	0.0	1.9	7.9	0.0	0.0
	Stdev.	0.5	0.3	0.0	0.2	0.0	1.4	3.3	0.0	0.0
	CI	0.4	0.2		0.1		1.0	2.3		
Headwater Marsh (N = 5)										
64-33	6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SR-25	6	0.0	0.0	0.0	0.0	0.0	0.5	0.8	0.0	0.0
SR-26	6	0.0	0.0	0.0	0.0	0.0	2.2	0.0	0.4	0.0
SR-28	6	0.0	0.0	0.0	0.0	0.0	1.7	0.0	0.0	0.0
SR-29	6	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0
	Avg.	0.1	0.0	0.0	0.0	0.0	0.9	0.2	0.1	0.0
	Stdev.	0.1	0.0	0.0	0.0	0.0	1.0	0.3	0.2	0.0
	CI	0.1					0.9	0.3	0.2	
Headwater Marsh (N = 10)										
62-24	7	1.0	0.0	0.0	0.0	0.0	0.7	2.7	0.0	0.0
SR-17	7	0.0	0.0	0.0	0.0	0.0	4.6	0.0	0.6	0.0
SR-18	7	0.0	0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0
SR-19	7	1.3	1.5	0.0	0.0	0.0	2.4	0.5	0.0	0.0
SR-20	7	2.0	0.7	0.0	0.0	0.0	4.7	0.0	0.0	0.0
SR-21	7	0.0	1.7	0.0	0.0	0.0	1.6	0.6	0.0	0.0
SR-22	7	1.2	0.0	0.0	0.0	0.0	2.2	1.1	0.0	0.6
SR-23	7	1.0	0.0	0.0	0.0	0.5	1.1	0.5	0.5	0.0
SR-24	7	0.9	0.0	0.0	0.0	0.0	1.4	1.4	0.5	0.0
SR-30	7	1.2	0.0	0.0	0.0	0.6	2.4	0.0	0.0	0.6
	Avg.	0.9	0.4	0.0	0.0	0.1	2.4	0.7	0.2	0.1
	Stdev.	0.7	0.7	0.0	0.0	0.2	1.4	0.9	0.3	0.3
	CI	0.4	0.4			0.1	0.8	0.5	0.2	0.2
Brackish Marsh (N = 9)										
62-25	8	0.6	0.0	0.6	0.0	0.0	1.1	0.0	0.6	0.6
62-30	8	1.9	0.0	0.6	0.0	0.0	8.3	0.6	0.6	0.6
64-18	8	2.1	0.0	0.0	0.0	0.0	3.7	0.5	0.0	0.0
64-22	8	0.6	0.0	0.0	0.0	0.0	2.8	4.5	0.0	0.0
HR-01	8	1.7	0.9	0.0	0.0	0.0	4.3	0.0	0.0	0.0
HR-02	8	0.6	0.0	0.0	0.0	0.0	1.9	0.0	0.6	0.0
JR-01	8	0.0	0.4	0.0	0.0	0.0	0.0	0.0	8.5	0.0
TB-01	8	1.2	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0
TB-02	8	3.0	0.0	0.0	0.0	0.0	2.4	1.2	0.0	0.0
	Avg.	1.3	0.1	0.1	0.0	0.0	2.8	0.8	1.1	0.1
	Stdev.	1.0	0.3	0.3	0.0	0.0	2.4	1.5	2.8	0.3
	CI	0.6	0.2	0.2			1.6	1.0	1.8	0.2
Brackish Marsh (N = 5)										
62-26	9	1.3	0.0	0.0	0.0	0.0	32.1	1.9	0.0	0.0
62-33b	9	0.9	0.0	0.0	0.0	0.0	2.8	0.0	2.8	0.0
62-35	9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	0.0
64-09H	9	0.6	0.0	0.6	0.0	0.0	6.9	0.6	0.0	0.0
64-14	9	0.6	0.6	0.0	0.0	0.0	1.2	1.8	1.2	0.0
	Avg.	0.7	0.1	0.1	0.0	0.0	8.6	0.9	1.1	0.0
	Stdev.	0.5	0.3	0.3	0.0	0.0	13.4	0.9	1.2	0.0
	CI	0.4	0.2	0.2			11.7	0.8	1.0	
Upland (N = 4)										
62-27	10	1.1	0.0	0.0	0.0	0.6	72.5	0.0	2.3	0.0
62-28	10	0.6	0.0	0.6	0.6	0.0	55.4	1.3	0.0	0.0
62-29	10	1.7	0.0	0.0	0.0	0.0	87.4	0.6	0.0	0.0
EE-11	10	0.0	0.0	0.6	0.0	0.0	73.4	0.0	0.6	0.0
	Avg.	0.9	0.0	0.3	0.2	0.2	72.2	0.5	0.7	0.0
	Stdev.	0.7	0.0	0.3	0.3	0.3	13.1	0.6	1.1	0.0
	CI	0.7		0.3	0.3	0.3	12.8	0.6	1.1	

Table 1.—Continued Extended.

<i>Hame- lia</i>	<i>Rhus</i>	<i>Myrt- aceae</i>	<i>Osmunda</i>	<i>Poly- podium</i>	<i>Eric- aceae</i>	<i>Sphag- num</i>	<i>Ulmus</i>	cf. <i>Thom- sono- pollis</i>	<i>Nuphar</i>	<i>Rhab- daden- ia</i>	<i>Pteris</i>	<i>Liquid- amber</i>	<i>Pinus</i>	Other	Grains count- ed	Grains used for stats
0.0	0.0	0.0	2.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.2	21.3	178	131
0.0	0.0	0.0	0.3	3.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31.6	30.1	301	195
0.0	0.0	0.0	0.5	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	24.6	24.4	195	138
0.0	0.0	0.0	2.6	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.8	18.7	155	118
0.0	0.0	0.0	1.8	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.9	21.0	218	161
0.0	0.0	0.0	0.0	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.2	32.2	241	151
0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.0	21.8	261	191
0.0	0.0	0.0	0.5	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.6	20.4	218	163
0.0	0.0	0.0	1.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.7			
0.0	0.0	0.0	1.1	1.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6			
			0.7	0.9									3.2			
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.2	12.5	179	157
0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	1.9	3.7	375	361
0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.9	6.7	231	216
0.0	0.0	0.0	11.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.9	8.4	242	222
0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.6	2.5	307	299
0.1	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	3.7			
0.1	0.0	0.0	4.8	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	2.7			
0.1			4.2						0.1				2.3			
0.0	0.0	0.0	2.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.3	11.7	300	244
0.0	0.0	0.0	1.8	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	10.2	10.9	176	144
0.0	0.0	0.0	6.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.5	7.9	168	143
0.0	1.5	0.0	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.0	13.3	200	159
0.0	0.0	0.0	10.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.4	9.6	149	124
0.0	1.1	0.6	7.0	0.6	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	7.0	3.9	185	165
0.0	0.0	0.6	2.9	0.0	0.0	0.0	0.0	0.0	0.6	0.0	1.1	0.0	4.5	2.1	178	162
0.0	0.0	0.5	4.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.4	5.3	182	160
0.0	0.0	0.0	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.6	3.5	220	197
0.0	0.0	0.6	4.8	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0	3.6	7.1	168	144
0.0	0.3	0.2	5.2	0.1	0.0	0.1	0.0	0.1	0.2	0.0	0.1	0.0	6.7			
0.0	0.6	0.3	2.6	0.2	0.0	0.2	0.0	0.2	0.4	0.0	0.3	0.0	2.4			
	0.3	0.2	1.6	0.1		0.1		0.1	0.3		0.2		1.5			
0.0	0.6	0.0	1.7	19.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	9.0	13.2	n/a	n/a
0.0	0.0	0.0	1.3	7.6	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	7.6	6.3	n/a	n/a
0.0	0.0	0.0	10.1	6.4	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	11.1	8.0	n/a	n/a
0.0	0.0	0.0	2.3	6.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	19.2	18.6	n/a	n/a
0.0	0.0	0.0	4.4	7.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.1	4.3	n/a	n/a
0.0	0.0	0.0	3.8	3.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.8	7.2	n/a	n/a
0.0	0.0	0.0	8.2	19.2	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.0	4.1	3.1	271	241
0.0	0.0	0.0	1.2	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.7	5.0	n/a	n/a
0.0	0.6	0.0	0.6	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.5	4.9	n/a	n/a
0.0	0.1	0.0	3.7	8.3	0.0	0.0	0.0	0.1	0.0	0.1	0.0	0.0	9.0			
0.0	0.3	0.0	3.3	6.5	0.0	0.0	0.0	0.2	0.0	0.2	0.0	0.0	4.5			
	0.2		2.2	4.3				0.1		0.1			3.0			
0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.2	10.9	n/a	n/a
0.0	0.0	0.0	2.8	6.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.6	34.2	n/a	n/a
0.0	0.0	0.0	0.0	54.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	5.9	n/a	n/a
0.0	0.0	0.0	0.6	6.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.9	2.6	n/a	n/a
0.0	0.0	0.0	0.6	6.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.7	11.7	168	133
0.0	0.0	0.0	0.8	14.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.2			
0.0	0.0	0.0	1.2	22.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.7			
			1.0	19.5									3.2			
0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	12.7	n/a	n/a
0.0	0.0	0.0	0.6	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.0	15.6	n/a	n/a
0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.6	2.1	n/a	n/a
0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.3	7.2	n/a	n/a
0.0	0.0	0.0	0.2	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	3.2			
0.0	0.0	0.0	0.3	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.0	2.7			
			0.3	0.6							0.3		2.7			



Text-figure 3.—Dendrogram illustrating associations of surface pollen and spore categories. Four cluster groupings are based on a Chi-squared distance of ~2.8.

nus. Cluster D contains *Rhizophora*, *Conocarpus*, *Laguncularia*, *Avicennia*, and *Batis* (Text-fig. 3).

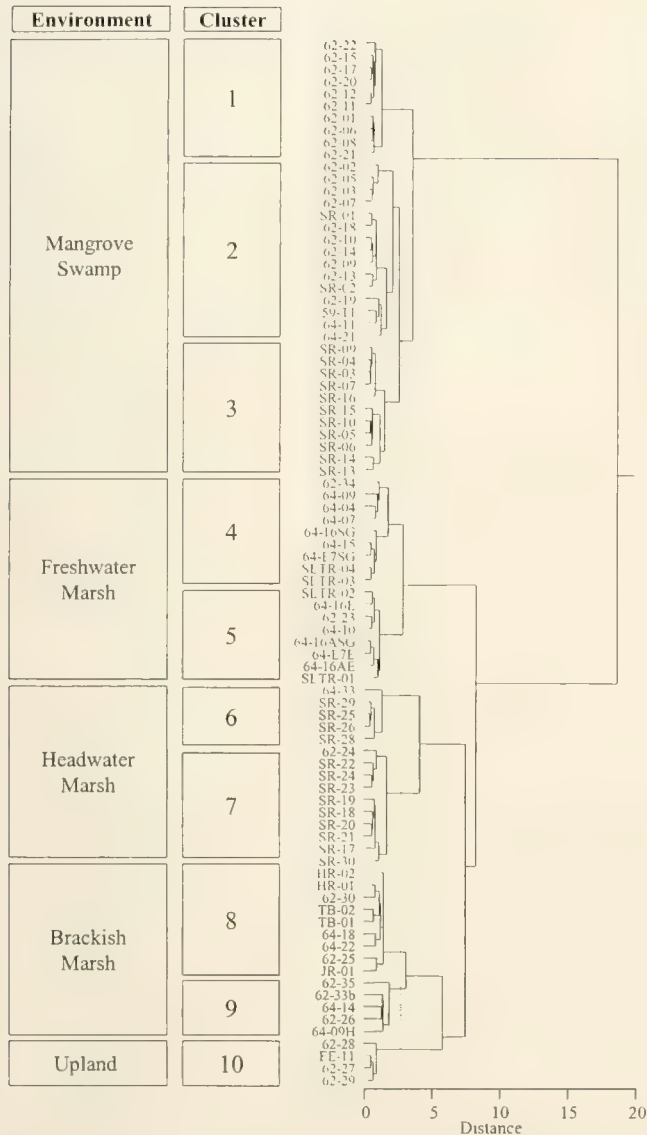
Cluster A contains taxa that are generally found in lower frequencies than those of other clusters (Table 1). Sub-cluster A1 includes taxa that have very low pollen frequencies and commonly appear in <2% of the sample sites. In addition, there are no clear patterns of spatial distribution for these taxa. The taxa in sub-cluster A2 appear in slightly higher frequencies than those of sub-cluster A1, but are still generally rare with no clear spatial distribution. The taxa in sub-cluster A3 are more common than the taxa in the other two sub-clusters, appearing in 30–50% of the sites. In addition, these taxa tend to occur in the freshwater marsh (slough), freshwater marsh with hammocks, and brackish marsh vegetation communities (Text-fig. 2). Cluster B is comprised of only chenopods. Chenopods are correlated most strongly with sites in the freshwater marsh—slough vegetation community (Text-fig. 2). However, they occur at all sites and tend to have an

inverse relationship with abundances of *Rhizophora*. Riegel (1965) also noted this relationship. Cluster C consists of taxa that are generally more abundant than those of cluster A and are consistently found at approximately 50% of the sample sites. In addition, taxa from cluster C show a strong spatial correlation with the freshwater marsh—slough and freshwater marsh with hammocks vegetation communities (Text-fig. 2). Finally, cluster D is comprised of taxa that are dominant in mangrove swamp and brackish marsh vegetation communities (Text-fig. 2).

Cluster Analysis of Sample Sites

The dendrogram from cluster analysis of the 86 surface samples can be divided into ten distinct cluster groups (Text-fig. 4). Samples in clusters 1, 2 and 3 are from locations in the mangrove swamp vegetation community and the margin of the brackish marsh vegetation community near the mangrove swamp. Cluster 1 is comprised of samples 62-01, 62-06, 62-08, 62-11, 62-12, 62-15, 62-17, 62-20, 62-21, and 62-22. These samples are from locations that are 1 to 2 kilometers from the coast (Text-fig. 2). Cluster 2 is comprised of samples 62-2, 62-3, 62-5, 62-7, 62-9, 62-10, 62-13, 62-14, 62-18, 62-19, 64-11, 64-21, SR-01, SR-02, and 59-T1. These samples are generally from sites along the coastal margin of the mangrove swamp (Text-fig. 2). Samples in cluster 2 have 35 taxa present, the widest variety of any cluster. Cluster 3 is comprised of samples SR-03 to SR-07, SR-09, SR-10, and SR-13 to SR-16. These samples are from sites along the mouth of the Shark River where there is a strong marine influence. The three clusters are dominated by mangroves (*Rhizophora*, *Avicennia*, and *Laguncularia*), *Batis*, chenopods (pigweed family), *Conocarpus*, and Compositae (aster family) pollen types. The frequency of *Rhizophora* in cluster 1 is 20% higher on average than in clusters 2 and 3. Cluster 2 samples differ primarily from cluster 1 by having higher frequencies of *Avicennia* and chenopods. Cluster 3 differs from clusters 1 and 2 by possessing more triporates, chenopods, and *Conocarpus* (Table 1).

Clusters 4 and 5 contain samples distributed throughout the freshwater marsh-slough, freshwater marsh with hardwood hammocks, and freshwater marsh with cypress hammocks vegetation communities (Text-fig. 2). Cluster 4 is comprised of samples 62-34, 64-04, 64-07, 64-09, 64-E7SG, 64-15, 64-16-SG, SLTR-03, and SLTR-04. Cluster 5 is comprised of samples 62-23, 64-E7E, 64-10, 64-16AE, 64-16ASG, 64-16E, SLTR-01, and SLTR-02. Although neither cluster occurs exclusively in a single vegetation community, samples in cluster 4 are primarily from the freshwater marsh with hardwood ham-



Text-figure 4.—Dendrogram illustrating association of surface sample cluster groups to environments. Ten clusters are designated based on a Chi-squared distance of ~ 2 (dashed line).

mocks and freshwater marsh with cypress hammocks vegetation communities, while those in cluster 5 are mainly from the freshwater marsh slough vegetation community. The dominant pollen types associated with freshwater marshes are chenopods, triporates, *Nymphaea*, *Sagittaria*, cf. *Ovoidites*, Compositae, and Cyperaceae (sedge family). Both of these clusters contain a wide variety of freshwater-dependent species, but chenopod abundances are approximately 33% higher in cluster 5 (Table 1).

Samples from clusters 6 and 7 are from sites located near the transition between the Everglades Depression and the mangrove swamp (Text-fig. 1). Although this area is designated as part of the brackish marsh veg-

etation community by Riegel (1965) (Text-fig. 2), Riegel (1965) also describes this area as a unique zone called the headwater marsh. The assignment of headwater marsh will be used to designate this area in this study as well. Cluster 6 is comprised of samples 64-33, SR-25, SR-26, SR-28, and SR-29, whereas cluster 7 is comprised of samples 62-24, SR-17 to SR-24, and SR-30. Samples in cluster 6 were obtained from locations along the margin between the freshwater marshes and brackish marsh, while samples in cluster 7 were selected from a more seaward position within the brackish marsh vegetation community (Text-fig. 2). The dominant pollen types associated with the headwater marsh are *Rhizophora*, chenopods, triporates, *Conocarpus*, and *Osmunda* (ferns). Cluster 6 samples have more than twice the average frequency of chenopods of cluster 7, whereas cluster 7 samples display a marked increase in *Rhizophora* and triporates (Table 1).

Cluster 8 groups samples from within the brackish marsh vegetation communities. This cluster includes samples HR-01 and HR-02, TB-01 and TB-02, JR-01, 62-25, 62-30, 64-18, and 64-22. Taxa common to the brackish marsh (i.e., *Rhizophora*, triporates, chenopods, *Polypodium* (ferns), *Conocarpus*, and Cyperaceae) dominate these samples. However, there is a wide diversity of taxa present in this cluster (Table 1).

Cluster 9 contains samples that are from the freshwater marsh with hardwood hammocks and freshwater marsh with cypress hammocks vegetation communities, but are grouped with the brackish marsh cluster. This cluster contains samples 62-26, 62-33b, 62-35, 64-09H, and 64-14. These samples include a variety of common freshwater species such as *Sagittaria*, *Umbelliferae*, and *Salix* (willow family), but they have more Compositae and less *Pinus* pollen than is found in the freshwater marshes. Although these samples contain a variety of taxa, each has an individual taxon that comprises at least 25% or more of the sample and does not conform to any common dominant species distribution found in other cluster groups (Table 1). For example, 27.4% of sample 64-14 is *Cephalanthus* (Buttonbush) and 26.4% of sample 64-09H is *Salix*.

Cluster 10 contains samples from sites along the Atlantic Coastal Ridge within the freshwater marsh with cypress hammocks vegetation community. This cluster contains samples 62-27 to 62-29, and EE-11. The dominant taxon associated with these sites is *Taxodium*, although there are also a variety of freshwater components present in these samples (i.e., Gramineae, Cyperaceae, and Compositae) (Table 1).

Discriminant Analysis

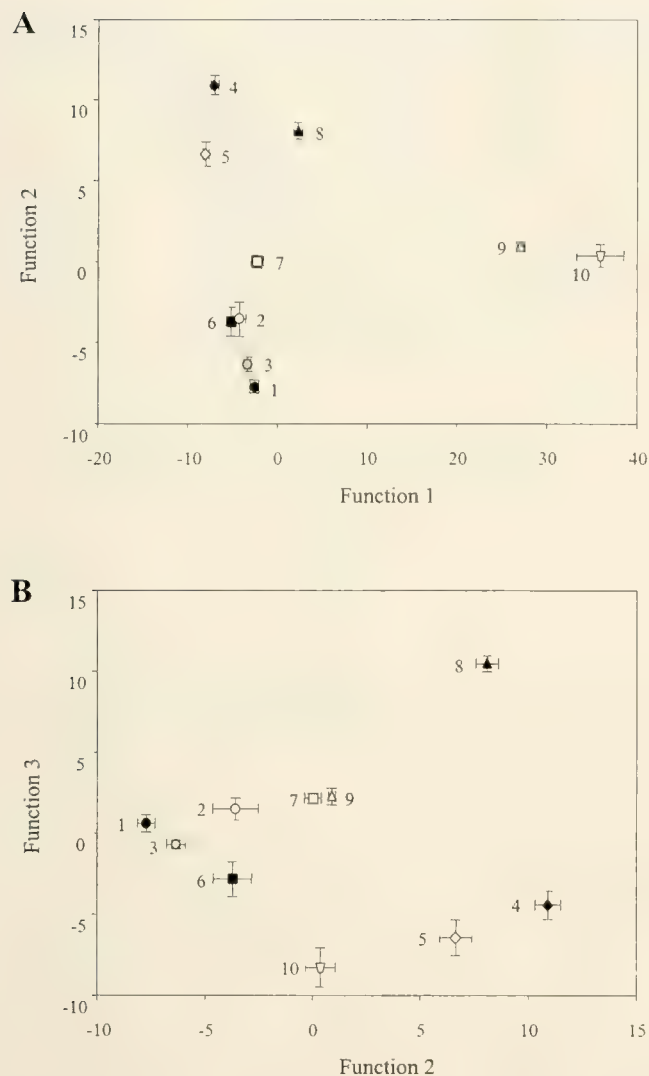
Discriminant analysis correctly assigned all 86 samples to the environmental groups delineated by cluster

Table 2.—Pooled within-groups correlations (loadings) between taxa and discriminant functions. The 18 key contributing taxa are highlighted.

Taxa	Function 1	Function 2	Function 3	Function 4
<i>cf. Ovoidites</i>	−0.05813	0.22115*	−0.21270	−0.06030
Triporates	−0.00777	0.21434*	0.21033	0.04846
<i>Ilex</i>	0.00486	0.07691	0.15489*	−0.01152
<i>Utricularia</i>	−0.02764	0.09736	−0.10737*	−0.00624
<i>Rhabdadenia</i>	0.00280	0.02188	0.05313*	−0.01507
Chenopods	−0.08009	−0.01600	−0.11739	0.46002*
<i>Taxodium</i>	0.21718	0.02709	−0.22441	−0.24851
Umbelliferae	0.03061	0.03766	−0.03234	0.5863
<i>Pinus</i>	−0.06834	0.12545	−0.13453	−0.12608
<i>Salix</i>	0.06142	0.01412	−0.00748	0.06407
<i>Cephalanthus</i>	0.04336	0.01126	−0.00109	0.08223
Composits	0.05375	0.01563	0.07966	0.06185
Sapotaceae	0.02655	0.00773	−0.00527	0.04206
<i>Rhizophora</i>	−0.05571	−0.30883	0.14459	−0.24059
<i>Ficus</i>	0.02610	0.03491	0.06934	0.02143
<i>Sphagnum</i>	−0.00375	−0.02183	0.00589	0.00232
<i>Quercus</i>	−0.00703	−0.00955	0.02081	−0.09885
<i>Myrta</i>	−0.00405	−0.00153	0.02151	0.10310
<i>Osmunda</i>	−0.00653	0.02657	0.05460	0.07390
<i>Fraxinus</i>	−0.00419	0.01061	0.04842	0.01722
<i>Nuphar</i>	−0.00428	−0.00930	0.00679	0.05765
<i>Nyssa</i>	0.02168	0.00030	−0.01830	0.01646
Caryophyllaceae	−0.00337	−0.01131	0.02565	−0.00836
<i>Laguncularia</i>	−0.01176	−0.05997	0.01209	−0.06271
<i>Carya</i>	0.00979	−0.01318	−0.02525	−0.03736
<i>Rhus</i>	−0.00284	−0.00467	0.03766	0.02378
<i>Pteris</i>	0.01606	0.00022	−0.01355	0.01219
<i>Rapanea</i>	−0.00428	0.03605	0.02974	0.00614
Ericaceae	−0.00287	−0.01593	−0.00225	−0.01830
<i>cf. Thomsonopollis</i>	−0.00258	0.03484	0.03885	0.00052
<i>Conocarpus</i>	−0.01460	−0.04109	0.14725	−0.09632
<i>Avicennia</i>	−0.02068	−0.11662	0.00641	−0.08752
<i>Anacardium</i>	−0.01116	−0.04637	0.00337	−0.04570
<i>Batis</i>	−0.00755	−0.04279	0.00075	−0.01688
<i>Polypodium</i>	0.04074	0.04546	0.05585	0.02431
Cyperaceae	0.00343	0.14085	0.09104	−0.04395
<i>Typha</i>	0.00558	0.05675	0.07508	−0.01937
Gramineae	0.00381	0.04199	0.03805	−0.03976
<i>Vitis</i>	0.02567	0.03047	0.04343	−0.00396
<i>Nymphaea</i>	−0.03497	0.08198	−0.12149	0.01812
<i>Sagittaria</i>	−0.01212	0.08797	−0.08782	0.07566
<i>Hamelia</i>	−0.00513	−0.00912	−0.01654	0.06530
<i>Ulmus</i>	−0.00701	0.02828	−0.02115	−0.01904
<i>Alnus</i>	0.00442	0.02143	−0.00730	−0.05957
<i>Eugenia</i>	0.00908	0.03237	0.03283	−0.01658
<i>Polygona</i>	0.04516	0.01269	−0.03082	0.06516
<i>Morus</i>	−0.00386	0.03707	−0.00408	−0.00298

analysis. The first four discriminant functions account for 92.5% of the variance in the data set and display high canonical correlations of 0.996, 0.989, 0.981, and 0.971 respectively, underscoring the effectiveness of the functions in discriminating between cluster groupings. The function loadings from the first four functions indicate that the surface cluster groupings are strongly influenced by 18 key taxa (Table 2). *Taxodium*, the dominant genus of the freshwater marsh with cypress hammocks physiographic zone, and chenopods

are the statistically significant taxa on function 1. Significant taxa on function 2 include *cf. Ovoidites*, *triporates*, *Ilex*, *Utricularia*, *Pinus*, *Rhizophora*, *Avicennia*, *Cyperaceae*, *Nymphaea*, and *Sagittaria*. Important taxa on function 3 are *cf. Ovoidites*, *triporates*, *Ilex*, *Utricularia*, *chenopods*, *Taxodium*, *Pinus*, *Compositae*, *Rhizophora*, *Conocarpus*, *Cyperaceae*, *Typha*, *Nymphaea*, and *Sagittaria*. On function 4, *chenopods*, *Taxodium*, *Pinus*, *Cephalanthus*, *Rhizophora*, *Quercus*, *Osmunda*, *Conocarpus*, *Avicennia*, and *Sagittaria*



Text-figure 5.—(A) Plot of means and 95% confidence intervals for environmental cluster groups on discriminant functions one and two. (B) Plot of means and 95% confidence intervals for environmental cluster groups on discriminant functions two and three. Numbers refer to cluster groups in Text-figure 4. The symbol used to identify cluster group 7 (Figure A) encompasses the 95% confidence interval bars for that group.

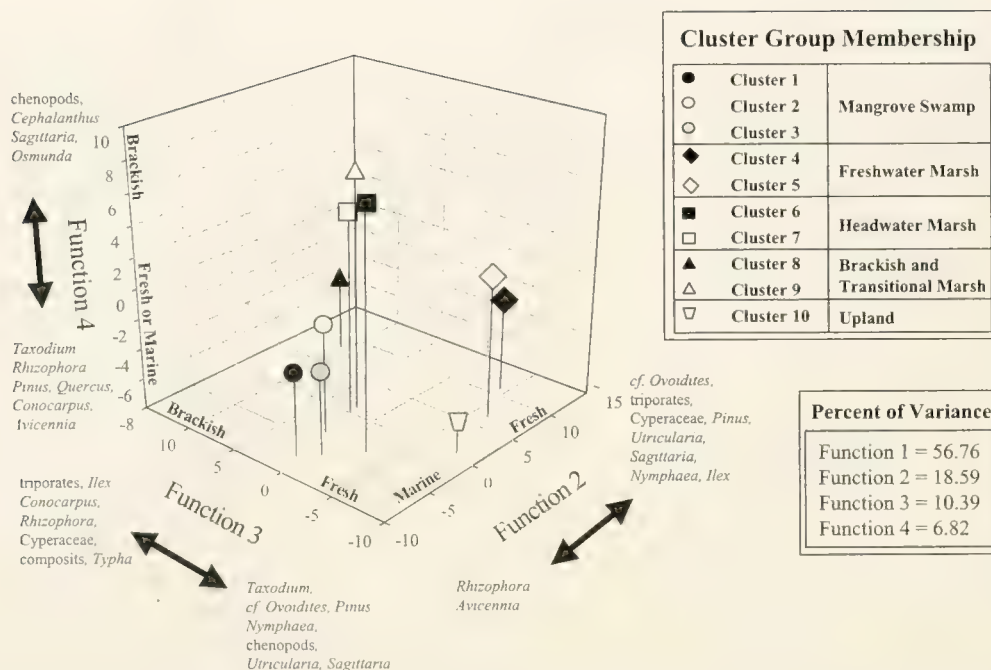
contribute most to group separation. Means and 95% confidence intervals for each group are plotted in Text-figure 5. A plot of discriminant score group means in three-dimensional discriminant function space displays broad spatial separations that underscore the statistical distinctiveness of the environmental groupings obtained from cluster analysis (Text-fig. 6).

DISCUSSION OF SURFACE POLLEN ZONATION

Visual inspection of the pollen data matrix sorted by site and taxonomic/morphologic groupings derived from cluster analysis (Table 1) indicates that there is a large amount of overlap in the species composition

of the environmental cluster groups. Individual pollen and spore taxa typically are not environmentally restricted so that no single pollen or spore type can be used to characterize a particular environment. *Rhizophora* pollen, for instance, is most abundant in mangrove swamp clusters where it comprises from 16 to 66% of samples. However, it contributes as much as 17% to samples from brackish marsh cluster 8 and as much as 29% to samples from the headwater marsh cluster 7. Chenopods are most common in samples from the headwater marsh clusters with abundances ranging between 15 and 90%. However, they also comprise 7 to 47% of samples from the freshwater marsh clusters. Similarly, triporates are most abundant in samples from the brackish marsh clusters, where they comprise 11 to 23% of the samples, but they comprise as much as 21% of samples from freshwater marsh cluster 4. Because of these occurrence patterns, visually determined associations of taxa may not be reliable indicators of environments. Riegel (1965) and Kuehn (1980) both relied on the appearance of *Typha* (cattail) and *Conocarpus* in vertical sequences to indicate an environmental shift to a brackish marsh. Discriminant analysis indicates that *Conocarpus* is an important component of the brackish marsh. However, our results do not indicate that the abundances of these species co-vary and suggest that the mere presence of these species is not a reliable environmental indicator. In contrast, Rich *et al.* (1982) interpret cf. *Ovoidites* to be an indicator of freshwater environments. Statistical analysis confirms that cf. *Ovoidites* is an important species of the freshwater marsh, but this interpretation is strengthened by the co-occurrence of cf. *Ovoidites* with *Sagittaria*, *Nymphaea*, *Utricularia* and *Umbelliferae* (hornwort), all of which are aquatic species (Text-fig. 3; Table 1). Pollen from the genus *Pinus* has a ubiquitous distribution because it is transported readily throughout the system by both wind and water (Habib *et al.*, 1994). Although it is generally most abundant near its origin in the Pine-Upland vegetation community, the presence of *Pinus* in all other vegetation communities, and its tendency to concentrate along the coast because of fluvial and marine transport, limits its usefulness. However, a study in Taylor Slough (which drains a small portion of the southern Everglades into Florida Bay) indicates that *Pinus* pollen comprises a significant proportion of samples and may be a useful taxon for paleoenvironmental interpretation there (Willard and Holmes, 1997). Similarly, trees of the genus *Quercus* are physically restricted to freshwater uplands. However, *Quercus* pollen tends to be widespread and present in low abundances, which may also limit its use for environmental interpretation.

As discussed above, numerically dominant pollen



Text-figure 6.—Three-dimensional plot of environmental cluster-group discriminant-score means with salinity regimes and key taxa displayed on each axis. Key taxa were identified by running stepwise iterations of discriminant analyses to identify the threshold where 100% discrimination was no longer achieved.

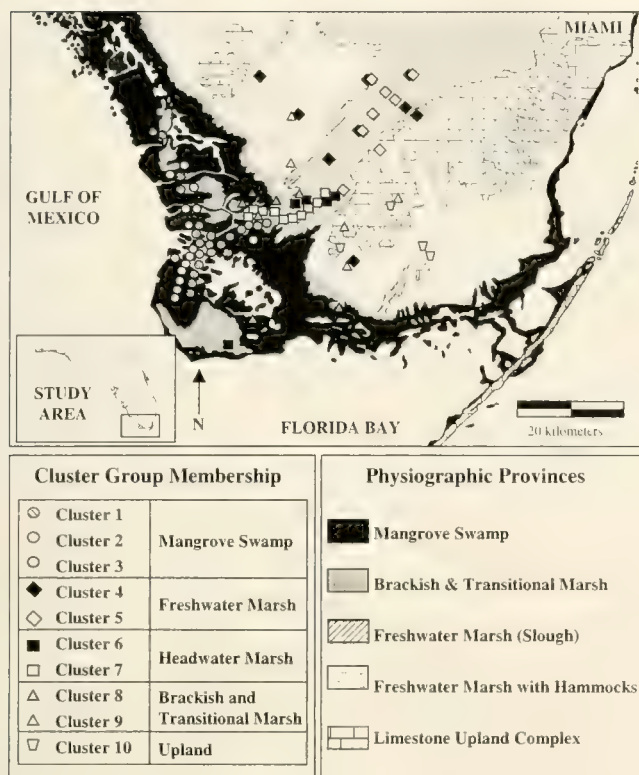
taxa are not restricted to a given cluster. Of note is also the fact that several species are not present in certain environments (Table 1). For example, *Avicennia* never occurs in the freshwater marshes. *Laguncularia* and *Vitis* (wild grape) pollen are extremely rare in the freshwater marshes, appearing in low numbers in only one sample. *Cephalanthus* and *Salix* are not present in the mangrove swamp or headwater marsh. However, other pollen and spore types that are restricted to one, or even two cluster groups, for example *Ericaceae*, are uncommon and comprise less than 1% of any given sample. Thus, their presence appears to be very sensitive to sampling and preparation procedures and very large sample volumes and counts would be required to be certain that their absence reflects environmental or depositional conditions. Additional problems may occur in that many rare pollen types generally comprise less than 2% of a sample and may not be present in statistically significant numbers in small samples. In most cases, the identification of a given environment cannot be based on the presence or absence of any single taxon and multivariate statistical analysis of pollen assemblages is necessary.

The surface sample groupings obtained from cluster analysis do, however, display a spatial distribution that is strongly correlated with the physiographic provinces of the study area (Text-fig. 7). This is evident when the sample sites (from Text-fig. 2) are categorized by

clusters (from Text-fig. 4) and overlaid on the physiographic map of the study area (Text-fig. 1).

In samples from the Mangrove Swamp physiographic province, there is a strong correlation between the frequency of *Rhizophora*, *Avicennia*, chenopods, triporates and *Conocarpus* in a given sample and the elevation, salinity, and proximity to major rivers from which samples were taken. Cluster 1 contains samples that are located approximately 1 km from the current shoreline along tidal channel margins where *Rhizophora* is dominant. These samples contain an average of 20% more *Rhizophora* than samples in the other mangrove swamp clusters. Cluster 2 samples are from areas along the coastal margin where there is more variability in substrate type, tidal influence, and elevation than is seen in cluster 1 areas. This variability is reflected in the increased frequency of mangrove forest taxa (*Avicennia*, *Laguncularia*, and *Conocarpus*) in cluster 2 samples. Cluster 3 contains samples with more triporate and *Conocarpus* pollen than samples in cluster 1 and 2. The samples in cluster 3 are from locations along the mouth of the Shark River, a primary route of freshwater delivery to the Gulf of Mexico. Therefore, it is reasonable to expect taxa common in brackish and freshwater marsh communities upstream to be present in cluster 3 samples.

Differences between clusters 4 and 5, from the freshwater marshes, are less evident than for other



Text-figure 7.—Overlay of sample site cluster groupings on physiographic map of southwest Florida showing strong correlation between environmental pollen clusters and physiographic provinces. Clusters 1, 2, and 3 are the mangrove swamp; clusters 4 and 5 are the freshwater marsh; clusters 6 and 7 are the headwater marsh; clusters 8 and 9 are the brackish marsh; and cluster 10 is the upland complex.

clusters. The abundance of a variety of freshwater-dependent taxa such as *Nymphaea*, cf. *Ovoidites*, and *Utricularia* assist in delineating this pollen zone, but compositional differences between the slough and adjacent marshes with hammocks result primarily from a large increase in the frequency of chenopods in the slough. Riegel (1965) attributed the dominance of chenopods and *Nymphaea* in the slough to their need for a higher water table in this low-lying area.

Differences in the headwater marsh clusters are based on changes in the frequency of *Rhizophora* and chenopods. Chenopods comprise more than 60% of samples from the headwater marsh (cluster 6) and are less dominant in cluster 7. *Rhizophora*, which comprises less than 2% of any of the samples in cluster 6, increases to an average of 16% in cluster 7. The increase in *Rhizophora* occurs in samples nearer to shore where the slough shifts to channels and *Rhizophora* is localized along the margins.

Samples from the brackish marsh, cluster 8, contain a wide variety of taxa. Tidal variability as well as fluctuations in freshwater and marine input strongly influ-

ence the taxa that can survive in the brackish marsh zone. The pollen spectrum resembles the mixture of taxa that result from *in situ* deposition in the brackish marsh (i.e. triporates, *Conocarpus*, Cyperaceae, *Osunda*, and *Polypodium*) plus components from the adjacent mangrove swamp and freshwater marsh environments. Many samples are dominated by individual taxa that do not occur in high frequencies elsewhere. These samples are grouped primarily in cluster 9 where individual taxa comprise 25% or more of the pollen totals. Each of these species is associated with the hardwood hammocks of the freshwater marsh (i.e. *Cephalanthus*, *Taxodium*, and *Salix*). It is likely that the broad distribution of taxa in conjunction with the low frequency of mangrove swamp taxa, resulted in the strong association of these samples with the brackish marsh rather than with freshwater marshes.

The samples in cluster 10 are from the freshwater marsh with cypress hammocks vegetation community. Each sample contains at least 50% *Taxodium* pollen, confirming Riegel's (1965) conclusion that an abundance of this species is indicative of the parent vegetation and the environment in which it occurs.

The loadings from the first four discriminant functions indicate that the surface pollen cluster groupings, or zones, are strongly influenced by 18 key taxa (Table 2). When the taxa are plotted along the functions (Text-fig. 6) it is evident that they are organized by salinity regimes. Although, hydroperiod, elevation, and salinity control the distribution of taxa and limit the pollen spectra of a sample, the functions only clearly display the salinity regimes when groups of taxa are arrayed on each axis towards the regime where they provide their strongest contribution. Text-figure 6 displays functions 2, 3, and 4 with the key taxa that drive each function towards the different regimes. Function 1, which is driven by *Taxodium* and, to a lesser degree by chenopods, was not plotted in the figure because it only excludes cluster 10 from the other groups (i.e., it serves to separate the *Taxodium* dominated hammocks of the freshwater marsh from other environments). Function 2 is driven by a suite of taxa from freshwater regimes at one end and dominant marine taxa on the other. Function 3 represents fresh to brackish regimes and helps separate the freshwater clusters from the others. Function 4 separates clusters located in and near the brackish areas from those with more freshwater and marine influences. The taxa that are listed at the end of each axis represent the key taxa for each regime that drive a cluster in either direction. Thus, a cluster's position on each axis is related directly to the key taxa that are present for each function. When the clusters are viewed on all three functions, domains representing different salinity

Table 3.—Range and average frequency of the 18 key taxa derived from discriminant analysis of the 86 surface sample sites.

Cluster		<i>Rhizophora</i>	<i>Avicennia</i>	<i>Conocarpus</i>	Chenopod	Cyperaceae	<i>Nymphaea</i>	<i>Utricularia</i>
1 Mangrove Swamp	Range	43.7–66.1	0–7.6	0–7.3	2.8–11.8	0–1.7	0–0.6	0–0
	Average	57.4	3	3	6.7	0.8	0.1	0
	Std. Dev	7.3	2.9	2.5	2.5	0.5	0.3	0
2 Mangrove Swamp	Range	11.7–49	0.6–9.6	1.7–11.8	5.9–28.4	0–4.3	0–1.3	0–0
	Average	31.5	4.3	4.1	14	0.7	0.3	0
	Std. Dev	10.2	2.9	2.6	6.7	1.1	0.5	0
3 Mangrove Swamp	Range	13.5–52.4	0–3.2	2.5–14.2	6.5–35.3	0–2.4	0–1.1	0–0.5
	Average	33.3	1.2	8.4	16.1	0.9	0.4	0.1
	Std. Dev	11.7	1.3	3.6	8.8	0.8	0.4	0.2
4 Freshwater Marsh	Range	0–1.2	0–0	0–1.2	2.8–17.3	2.8–12.3	0–8.9	0–1.8
	Average	0.3	0	0.5	9.7	6	3.2	0.7
	Std. Dev	0.5	0	0.4	5.8	2.8	3.7	0.6
5 Freshwater Marsh	Range	0–1.2	0–0	0–0.6	22.9–47.2	1.2–5.6	1.7–25.3	0–1.9
	Average	0.3	0	0.1	32.7	2.7	9.6	0.7
	Std. Dev	0.4	0	0.2	7.5	1.5	7.7	0.6
6 Headwater Marsh	Range	0–1.3	0–3.4	0–0.6	62.1–89.9	0.3–2.1	0–0.8	0–0
	Average	0.6	0.7	0.1	76.3	0.9	0.4	0
	Std. Dev	0.5	1.5	0.3	10.5	0.8	0.4	0
7 Headwater Marsh	Range	2.3–28.7	0–1.8	0–4	14.9–47.7	0.7–4.2	0–2.3	0–0.5
	Average	16.1	0.7	1.5	32.4	1.9	1	0.18
	Std. Dev	8.8	0.6	1.4	11.5	1.1	0.8	0.2
8 Brackish Marsh	Range	2.3–16.9	0–0.6	1.1–19.1	4.8–19.1	0.9–17	0–0.6	0–0
	Average	10.2	0.1	6.7	9.4	8	0.1	0
	Std. Dev	5.5	0.2	6.2	4.3	6	0.2	0
9 Brackish Marsh	Range	0–1.3	0–0	0–1.3	0.5–15.1	1.6–3.6	0–0.6	0–0.6
	Average	0.5	0	0.5	5.3	2.7	0.1	0.1
	Std. Dev	0.7	0	0.6	6	0.7	0.3	0.3
10 Upland	Range	0–0.6	0–0	0–0.6	0.6–17	0–4.1	0–0	0–0
	Avg	0.3	0	0.2	1.2	2.3	0	0
	Std. Dev	0.3	0	0.3	0.5	2	0	0

regimes are apparent (Text-fig. 6). Although hydroperiod, salinity and elevation are strongly correlated in the study area, hydroperiod and elevation differences do not appear to be controlling distributions that are identifiable in this form of multivariate statistical analysis.

A discriminant analysis of the surface sample data set based solely on the 18 key taxa produced 98.84% correct discrimination, with only one sample from cluster 2 misclassified as a member of cluster 3. This misclassification is a shift within the mangrove swamp environment and is not a complete reassignment to a different environment. These results indicate that analyses like this could potentially be completed using only the 18 key taxa in Table 3, although none of these taxa are restricted to a single cluster. Analysis of all of the taxa in a sample may be required to determine relationships between samples. Text-figure 8 is a generalized schematic of the Everglades physiographic provinces with the key pollen types that help delineate each area. This conceptual diagram can be used to determine the distribution and relative importance of the 18 key taxa in the different physiographic zones. A

primary reason for this is that a variety of taxa are present in relatively low abundances in some clusters such as the freshwater marsh clusters 4 and 5. This problem reiterates the need for high pollen counts. The suggested minimum count of 150 grains per sample used by Riegel (1965) is still very low.

PART B: APPLICATION TO VERTICAL SEDIMENTARY SEQUENCES

In order to assess the value of the approach for paleoecological interpretations, pollen data were collected for two cores. The first, from the coastal margin of the Harney River (referred to hereafter as 59-T1) was collected by Riegel (1965). The second, core 9411-7, was collected from the Gopher Key region for a sedimentologic study by Gelsanliter (1996) (Text-fig. 1). Both are long cores, taken to the Pleistocene bedrock surface and potentially contain sediments that record much of the late Holocene depositional history of southwest Florida.

Core Descriptions

The sedimentological description for core 59-T1 is presented in Riegel (1965). The core is 3.97 m in

Table 3.—Extended.

<i>Ilex</i>	<i>Triporates</i>	<i>Taxodium</i>	<i>Ovoidites</i>	<i>Pinus</i>	<i>Sagittaria</i>	<i>Compositis</i>	<i>Cephalan- thus</i>	<i>Quercus</i>	<i>Typha</i>	<i>Osmunda</i>
0-0	0-0	0-3.2	0-0	2-20.7	0-0	1.8-6.1	0-0	0-1.9	0-0.6	0-0.6
0	0	1.6	0	8.7	0	2.9	0	0.6	0.1	0.1
0	0	1.1	0	5.7	0	1.3	0	0.7	0.3	0.2
0-0.6	0-3.9	0-4.5	0-0.9	5.3-27.4	0-0.7	0-9.6	0-0.5	0-4.3	0-0.7	0-18.1
0	0.9	1.5	0.1	12.8	0.1	1.9	0	2.2	0.2	1.8
0.2	1.3	1.4	0.3	5.6	0.2	2.3	0.1	1.4	0.3	4.6
0-0.7	2.9-13.9	0-1.3	0-1.7	6.3-17.3	0-1.8	0.6-4.2	0-0	0-3.2	0-0.7	0-0
0.1	5.9	0.7	0.6	10.2	0.5	2.2	0	1.4	0.1	0
0.3	3	0.5	0.6	3.1	0.6	1.3	0	1.1	0.2	0
0-1.2	6.9-21.2	0.5-5.3	2.9-15.8	13.9-47.8	0.9-11.5	0.5-4	0-1.7	0.5-3.2	0-6.1	0-6.3
0.3	11.7	2.3	10.1	28.3	4.8	2.2	0.6	1.4	0.9	1.6
0.4	4.8	1.5	4.2	10.1	4.4	1.2	0.6	0.8	2	2.2
0-0	0.8-13.5	0-3.9	1.4-12.8	16.8-31.6	0.5-5	0-2.7	0-0.5	0-1.4	0-0.8	0-2.6
0	5.5	1.9	7.9	23.7	2.5	1	0.1	0.6	0.2	1
0	4.4	1.4	3.3	4.6	1.7	1	0.2	0.5	0.3	1.1
0-0	0-3.9	0-2.2	0-0.8	1.6-8.2	0-5.9	0-4	0-0.4	0-0.3	0-0.6	0-11.1
0	2	0.9	0.2	3.7	2.9	1.3	0.1	0.1	0.3	2.5
0	1.4	1	0.3	2.7	2.1	1.7	0.2	0.1	0.3	4.8
0-1.4	5.5-20.4	0.7-4.7	0-2.7	3.6-10.2	0.6-3.6	1-10.3	0-12.5	0-2	0-2.3	1.8-10.1
0.6	10.9	2.4	0.7	6.7	1.6	3.9	1.6	0.9	0.5	5.2
0.5	4.1	1.4	0.9	2.4	0.9	2.8	3.9	0.7	0.7	2.6
0-4.1	11.1-23.3	0-8.3	0-4.5	4.1-19.2	0-0.9	1.8-7.4	0-1.1	0-3	0-7.3	0.6-10.1
1.5	18.6	2.8	0.8	9	0.3	4.4	0.2	1.3	2.2	3.7
1.3	3.9	2.4	1.5	4.5	0.4	2.1	0.4	1	2.8	3.3
0-0	0.5-14.5	0-32.1	0-1.9	0.5-8.2	0-8.3	3.6-12.7	0.5-27.4	0-1.3	0-1.6	0-2.8
0	5.6	8.6	0.9	5.2	2.5	8.1	8.1	0.7	0.4	0.8
0	5.3	13.4	0.9	3.7	3.3	4.3	11.2	0.5	0.7	1.2
0-0.6	0.6-2.3	55.4-87.4	0-1.3	0.6-7	0-1.2	1.2-4.6	0-4.1	0-1.7	0-0.6	0-0.6
0.2	1.3	72.2	0.5	3.2	0.5	2.5	1.7	0.9	0.5	0.2
0.3	0.7	13.1	0.6	2.7	0.6	1.5	2.1	0.7	0.3	0.3

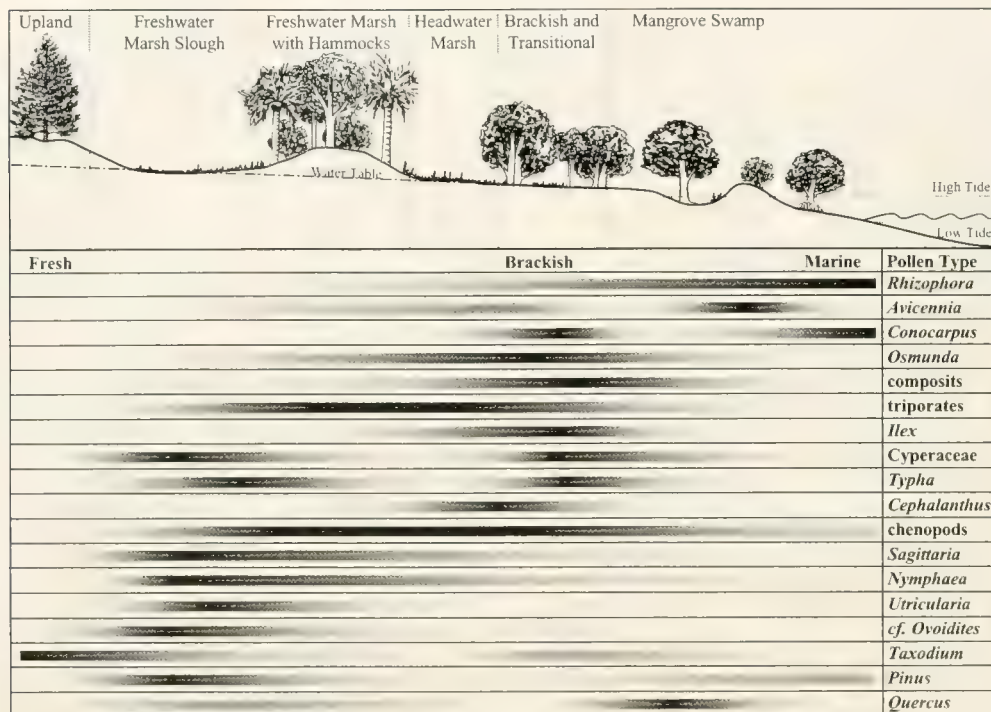
length (Text-fig. 9). Its base contains a mixed marl and peat (3.97 m to 3.73 m) overlain by a pure peat that grades into a muddy mangrove peat (3.73 m to 0.76 m), and is capped by organic-rich carbonate muds (0.76 m to the surface in 1965).

The sedimentological description of core 9411-7 is presented in Gelsanlter (1996). This core is 2.63 m in length (Text-fig. 10). The base of the core (between 2.63 m and 2.10 m) consists of quartz sands overlain by a red mangrove peat (between 2.10 m and 1.74 m). A gray mudstone to wackestone is present between 1.73 m and 1.50 m. Between 1.50 m and 1.37 m is a red mangrove peat overlain by a gray mudstone to wackestone (1.37 m and 0.97 m) that grades into a tan mudstone to wackestone (0.97 and 0.75 m). Capping the sequence, between 75 cm and the depositional surface in 1994, is a red mangrove peat.

Laboratory Methods for Pollen Analysis of Core Samples

Identification of pollen and spore types in the cores followed standard procedures (Moore *et al.*, 1991; Wood *et al.*, 1996). Core sub-samples of a known vol-

ume were taken with a 10-cm³ syringe, water content was determined, and bulk density calculated for subsequent count normalization. Organic content of previously dried sediment was estimated from weight loss on ignition at 450°C for 6 hours (Dean, 1974). Initially, 1 g sub-samples were processed for pollen concentration. However, the large quantity of organic material present in all samples yielded low pollen concentrations using standard processing techniques. Using standard methods on larger quantities of material (*i.e.*, >1 g) often resulted in incomplete digestion of organic debris that masked the presence of pollen. Therefore, multiple, smaller sub-samples of approximately 0.2 g to 0.25 g were dried, disaggregated and spiked with a *Lycopodium* yield tracer tablet to facilitate the calculation of absolute pollen concentrations (Stockmarr, 1971). *Lycopodium* tablets were dissolved and calcium carbonate was removed from the sample by the addition of 10% HCl. All samples were treated with HF in a hot water bath to remove silica. After neutralization of the acid, samples were dried and treated in a hot water bath with 5% KOH for 3 minutes. Samples were sieved with a 200 µm screen to remove large



Text-figure 8.—Conceptual diagram displaying the distribution of the 18 key taxa across the major physiographic zones of the study area. Shading on bars represents relative within-taxa frequency in a given environment (darker = more abundant).

organic detritus. After sieving, the samples were acetylated in a hot water bath for 3 minutes. After neutralization, pollen concentrates were dehydrated with alcohol, suspended in silicon oil, stained with safranin and mounted on microscope slides for examination.

Sample Counts

Pollen identification for core 9411–7 was completed at Indiana University/Purdue University at Indianapolis. Pollen grains were identified under incandescent and fluorescence light microscopy by comparing them to a reference set of tropical pollen consisting of herbarium samples from Everglades National Park, a set of modern pollen taxa provided by D. Kuehn (Western Kentucky University), and a computerized database. Under fluorescence, details of exine microstructure and ornamentation are enhanced thereby facilitating grain identification.

Core 59-T1 was processed and counted by Riegel (1965). Riegel (1965) indicates that standard preparation procedures were followed and counting was conducted on at least three slides per sample. For each site, Riegel (1965) attempted to count a minimum of 150 grains. Due to the scarcity of grains in some samples, on occasion, counting was stopped after a minimum of 100 grains. Riegel (1965) did not use marker grains; thus absolute pollen concentrations are not pre-

sented. In total, Riegel counted 28 samples for core 59-T1 (Table 4).

For core 9411–7 every attempt was made to count 300 grains for each sample interval. In total seventeen samples from this core were counted (Table 5). For most samples however, the scarcity of pollen necessitated lower counts (range 102 to 306). Most palynologists working in South Florida attempt to identify a minimum of 300 grains, although many data sets are characterized by low pollen sums of commonly around 150 grains (Riegel, 1965; Kuehn, 1980; and Willard and Holmes, 1997).

Statistical Analysis of the Core Data

Discriminant analysis was used to assign core samples to surface pollen zones, identified earlier in this paper, in order to identify environmental changes in the vertical sequences over time. The input data were the frequency counts. The data sets for the cores were reduced to the same 48 taxonomic and morphologic pollen and spore categories presented in the first section of this study. Discriminant function scores were calculated for each sample by transforming the original set of measurements into a single value on each function. Using these scores, each sample was assigned to the surface cluster group with which it was most sim-

Depth (cm)	C ¹⁴ Dates	Core Description	Cluster	Physiographic Zone
0	620 ± 150 ybp	Organic-rich Carbonate Muds	2	Mangrove Swamp (Coastal)
			2	Mangrove Swamp (Coastal)
			4	Freshwater Marsh with Hammocks
			2	Mangrove Swamp (Coastal)
			2	Mangrove Swamp (Coastal)
50		Muddy Peat with Mangrove Roots	2	Mangrove Swamp (Coastal)
			1	Mangrove Swamp (Inner)
			2	Mangrove Swamp (Coastal)
100			2	Mangrove Swamp (Coastal)
			2	Mangrove Swamp (Coastal)
			2	Mangrove Swamp (Coastal)
			2	Mangrove Swamp (Coastal)
			2	Mangrove Swamp (Coastal)
			1	Mangrove Swamp (Inner)
			2	Mangrove Swamp (Coastal)
150	2,830 ± 170 ybp	Red Mangrove Peat	1	Mangrove Swamp (Inner)
			1	Mangrove Swamp (Inner)
			1	Mangrove Swamp (Inner)
			2	Mangrove Swamp (Coastal)
			3	Mangrove Swamp (Channel)
			1	Mangrove Swamp (Inner)
			3	Mangrove Swamp (Channel)
			2	Mangrove Swamp (Coastal)
			8	Brackish
			8	Brackish
200		Mixed Marl and Peat	4	Freshwater Marsh with Hammocks
			8	Brackish
			8	Brackish
			8	Brackish
			8	Brackish
250				
300				
350				
400	4,080 ± 180 ybp			

Text-figure 9.—Stratigraphic column of core 59-T1 (modified from Riegel, 1965) and surface cluster group associations for samples. Sample depths are indicated in gray.

ilar. All multivariate statistical analyses were completed using SYSTAT version 6.0 (SPSS Inc. 1996).

Results for Vertical Sedimentary Sequences

The results of discriminant analysis of core 59-T1 with the surface pollen zone data set assigned samples 84–92 cm, 190–198 cm, 221–229 cm, 236–242 cm, 251–259 cm, and 297–305 cm to the mangrove swamp surface cluster group 1 (Text-fig. 9). Samples 0–8 cm, 8–15 cm, 38–45 cm, 53–61 cm, 69–77 cm, 99–107 cm, 114–122 cm, 130–138 cm, 145–153 cm, 160–168 cm, 175–183 cm, 205–213 cm, 266–272 cm, and 320–328 cm were assigned to the mangrove swamp surface cluster group 2. Samples 282–290 cm and 312–320 cm were assigned to the mangrove swamp surface cluster group 3. Samples 22–30 cm and 366–374 cm were assigned to the freshwater marsh surface cluster group 4. Samples 335–343 cm, 351–359 cm, 381–389 cm, and 389–397 cm were assigned to the brackish and transitional marsh cluster group 8 (Text-fig. 9).

The discriminant analysis of core 9411–7 with the surface data set grouped sample 69 cm with the mangrove swamp surface cluster group 1 (Text-fig. 10). Samples 35 cm, 46 cm, 58 cm, 104 cm, 120 cm, 130

Depth (cm)	Sediment Type	Age	Cluster	Physiographic Zone
10	Red Mangrove Peat	present	6	Headwater Marsh (Upper)
20			3	Mangrove Swamp (Channel)
30			2	Mangrove Swamp (Coastal)
40			2	Mangrove Swamp (Coastal)
50			2	Mangrove Swamp (Coastal)
60			2	Mangrove Swamp (Coastal)
70			1	Mangrove Swamp (Inner)
80				Excluded / Low Pollen Sum
90				Excluded / Low Pollen Sum
100			2	Mangrove Swamp (Coastal)
110	Gray Mudstone to Wackestone	2,390±60 YBP	2	Mangrove Swamp (Coastal)
120			2	Mangrove Swamp (Coastal)
130			2	Mangrove Swamp (Coastal)
140	Red Mangrove Peat		2	Mangrove Swamp (Coastal)
150			2	Mangrove Swamp (Coastal)
160	Gray Mudstone to Wackestone	2,880±60 C ¹⁴ YBP	2	Mangrove Swamp (Coastal)
170			2	Mangrove Swamp (Coastal)
180	Red Mangrove Peat	~3200 YBP		Excluded / Low Pollen Sum
190				
200			2	Mangrove Swamp (Coastal)
210	Quartz Sand		8	Brackish
220				
230				
240				
250				
260				
				Excluded / Low Pollen Sum
	Bedrock			

Text-figure 10.—Stratigraphic column of core 9411–7 (modified from Gelsanliter, 1996) and surface cluster group associations. Sample depths are indicated in gray.

cm, 145 cm, 155 cm, 165 cm, and 205 cm were grouped with the mangrove swamp surface cluster group 2. Sample 21 cm was grouped with the mangrove swamp surface cluster group 3. Sample 10 cm was grouped with the headwater marsh surface cluster group 6. Sample 248 cm was grouped with the brackish and transitional marsh surface cluster group 8. Samples 79 cm, 90 cm, and 188 cm were excluded from discriminant analysis because of low pollen counts (Text-fig. 10).

DISCUSSION

Discriminant analysis of samples from core 59-T1 with the surface data set indicates that the overall sequence went from basal brackish and freshwater marsh environments to dominantly mangrove swamp environments towards the present surface. These mangrove environments shifted from mixed mangrove environments to predominantly coastal environments upwards in the core. This sequence suggests an overall transgression of southwest Florida, an interpretation supported by Riegel (1965) and Spackman *et al.* (1966)

Table 4.—Pollen frequency data for core 59-T1.

Sample	<i>Rhizophora</i>		<i>Avicennia</i>		<i>Laguncularia</i>		<i>Conocarpus</i> Buttonwood	<i>Batis</i> Saltwort	Chenopods	Gramineae		Cyperaceae		<i>Typha</i> Cattail	<i>Nymphaea</i> Water Lilly	<i>Sagittaria</i> Arrowhead		Umbelliferae Parsley family
	Red Mangrove		Black Mangrove	White Mangrove						Grass family	Sedge family							
0-8 cm	30.7		6.1	8.9		2.4	0.0	9.2	1.2	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.6
8-15 cm	42.6		4.5	0.6		2.6	0.0	7.7	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6
22-30 cm	31.1		5.5	1.2		4.3	0.6	3.6	1.2	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
38-45 cm	40.1		7.7	2.2		1.6	0.0	5.6	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
53-61 cm	38.4		12.1	3.1		3.5	1.3	8.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
69-77 cm	42.7		14.6	0.7		1.1	1.8	4.0	0.0	0.0	0.7	0.0	0.0	1.1	0.7	0.7	0.0	0.0
84-92 cm	55.7		11.3	0.5		1.0	1.5	3.1	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99-107 cm	50.3		12.6	2.5		3.0	0.0	4.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0
114-122 cm	41.2		10.7	3.2		3.7	1.1	5.3	0.5	0.0	1.1	0.0	0.0	0.0	0.5	0.0	0.0	0.0
130-138 cm	43.6		9.9	3.3		3.8	0.9	4.8	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0
145-153 cm	47.2		6.8	1.2		1.9	8.7	0.6	1.9	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
160-168 cm	43.6		8.3	1.7		2.8	1.1	7.2	0.6	0.0	0.6	0.0	0.0	0.0	0.0	0.6	0.0	0.0
175-183 cm	38.7		23.1	1.1		0.5	0.0	5.9	1.1	0.0	0.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0
190-198 cm	47.3		7.3	1.5		2.0	0.0	11.3	1.5	0.0	1.0	0.0	0.0	0.0	1.0	0.5	0.0	0.0
205-213 cm	47.9		4.1	1.2		0.6	0.0	16.0	0.0	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0
221-229 cm	60.1		3.4	1.1		1.1	0.0	12.9	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
236-242 cm	67.0		3.4	0.6		1.1	0.0	9.7	0.6	0.0	0.6	0.0	0.0	0.0	0.0	0.6	0.0	0.0
251-259 cm	52.8		4.4	0.0		1.3	0.6	12.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0
266-272 cm	43.4		2.3	2.3		1.7	1.1	15.5	1.1	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
282-290 cm	46.3		0.6	0.6		0.6	1.2	14.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
297-305 cm	55.4		0.6	0.0		0.6	0.0	12.0	1.2	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
312-320 cm	48.8		1.2	0.0		0.0	0.0	11.6	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
320-328 cm	53.8		0.6	1.3		1.3	2.6	9.6	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.6	0.0	0.0
335-343 cm	13.3		0.5	0.5		2.0	0.0	17.2	0.0	0.0	17.2	0.0	0.0	3.0	0.5	0.0	0.0	0.0
351-359 cm	5.6		0.7	0.7		0.0	0.0	16.5	1.1	0.0	24.2	0.0	0.0	0.7	8.4	2.8	0.4	0.0
366-374 cm	2.1		0.0	0.0		0.5	0.0	12.4	1.6	0.0	9.3	0.0	0.0	0.5	9.8	3.1	0.5	0.0
381-389 cm	9.5		0.0	0.6		0.0	0.0	6.3	1.3	0.0	12.0	0.0	0.0	0.6	5.7	2.5	3.8	0.0
398-397 cm	11.2		2.4	0.0		0.0	1.2	7.7	1.8	0.0	12.4	0.0	0.0	0.0	5.9	2.4	0.6	0.0

Table 4.—Extended.

Sample	<i>Utricularia</i> Bladderwort	Compositae	Polygonaceae Smart weed	Caryophyllaceae	<i>Ilex</i> Holly	Salix Willow	<i>Morus</i>	<i>Ficus</i>	Triporates	<i>Eugenia</i>	<i>Cephalanthus</i>	<i>Fraxinus</i>
0-8 cm	0.0	3.0	0.0	0.0	0.6	0.0	0.6	0.6	1.9	0.0	0.0	0.0
8-15 cm	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	3.9	0.0	0.0	0.0
22-30 cm	0.0	1.8	0.0	0.0	0.0	0.6	0.0	0.6	2.4	0.6	0.0	0.0
38-45 cm	0.0	0.5	0.0	0.0	0.0	0.5	0.0	0.5	1.6	0.0	0.0	0.0
53-61 cm	0.0	0.8	0.0	0.0	0.0	0.4	0.0	0.0	0.8	0.0	0.4	0.0
69-77 cm	0.0	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.0	0.0	0.0	0.0
84-92 cm	0.0	0.5	0.0	0.0	0.0	0.5	0.0	0.5	0.5	0.0	0.0	0.0
99-107 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
114-122 cm	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
130-138 cm	0.0	1.0	0.0	0.0	0.0	0.5	0.0	0.5	0.5	0.0	0.0	0.0
145-153 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.6	0.0	0.0	0.0
160-168 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
175-183 cm	0.0	0.0	0.0	0.0	0.0	1.1	0.5	0.0	0.0	0.0	0.0	0.0
190-198 cm	0.0	1.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0
205-213 cm	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
221-229 cm	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
236-242 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.6	0.0	0.0	0.0
251-259 cm	0.0	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
266-272 cm	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.6	0.6	0.0	0.0	0.0
282-290 cm	0.0	0.6	0.0	0.0	0.0	0.0	0.6	0.6	1.1	0.0	0.0	0.0
297-305 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.2	0.0	0.0	0.0
312-320 cm	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.6	0.6	0.0	0.0	0.0
320-328 cm	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.6	1.8	0.0	0.6	0.0
335-343 cm	0.0	2.5	0.0	0.0	0.0	0.0	0.5	0.0	1.2	0.0	0.0	0.0
351-359 cm	0.4	4.3	0.0	0.0	0.0	0.0	0.0	0.4	1.0	0.0	0.0	0.0
366-374 cm	0.5	4.6	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0	0.0	0.0
381-389 cm	0.0	5.8	0.0	0.0	0.0	0.0	0.0	0.0	1.3	0.0	0.0	0.0
398-397 cm	0.0	3.6	0.0	0.0	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.0

Table 4.—Extended.

Sample	Sapotaceae	Quercus Oak	Anacardium	Alnus Alder	Carya	Nyssa	Taxodium Cypress	cf. <i>Ovoidites</i>	Vitis Grape	Rapanea	Hamelia	Rhus
0-8 cm	0.6	3.3	1.2	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0	0.0
8-15 cm	0.6	2.6	0.6	0.0	0.0	0.0	1.3	1.3	0.0	0.0	0.0	0.0
22-30 cm	0.0	2.4	1.8	0.0	0.0	0.0	1.2	0.0	0.0	0.0	0.6	0.0
38-45 cm	0.5	1.0	1.6	0.0	0.0	0.0	0.5	0.5	0.0	0.0	0.0	0.0
53-61 cm	0.4	0.9	1.3	0.0	0.0	0.0	2.2	0.0	0.0	0.0	0.0	0.0
69-77 cm	0.0	1.1	1.8	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0
84-92 cm	0.5	0.5	1.0	0.0	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0
99-107 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
114-122 cm	0.0	0.0	2.7	0.0	0.0	0.0	0.5	1.1	0.0	0.0	0.0	0.0
130-138 cm	0.0	1.9	1.4	0.0	0.0	0.0	1.4	0.0	0.0	0.0	0.0	0.0
145-153 cm	0.0	2.5	0.0	0.0	0.0	0.0	1.2	0.6	0.0	0.0	0.0	0.0
160-168 cm	0.0	2.9	1.1	0.6	0.0	0.0	1.7	0.0	0.0	0.0	0.0	0.0
175-183 cm	1.1	1.6	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
190-198 cm	0.5	0.5	1.5	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0
205-213 cm	0.0	1.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
221-229 cm	0.0	0.0	0.6	0.6	0.0	0.0	0.6	0.6	0.0	0.0	0.0	0.0
236-242 cm	0.0	0.6	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
251-259 cm	0.0	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
266-272 cm	1.7	0.6	0.6	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
282-290 cm	0.0	2.4	1.2	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
297-305 cm	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
312-320 cm	0.6	3.6	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
320-328 cm	0.0	1.9	0.0	0.6	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0
335-343 cm	0.0	2.4	0.0	0.0	0.0	0.0	0.0	0.5	0.0	0.0	0.0	0.0
351-359 cm	0.0	0.0	0.4	0.4	0.0	0.0	0.4	1.4	0.0	0.0	0.0	0.0
366-374 cm	0.0	0.5	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0
381-389 cm	0.0	2.5	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0
398-397 cm	0.0	3.6	0.0	0.0	0.0	0.0	1.2	4.7	0.0	0.0	0.0	0.0

Table 4. Extended.

Sample	Myrtaceae	<i>Osmunda</i>	<i>Polypodium</i>	Ericaceae Heath family	<i>Sphagnum</i>	<i>Ulmus</i> Elm	cf. <i>Thomsonopolis</i>	<i>Nuphar</i>	<i>Rhabdadenia</i>	<i>Pteris</i>	<i>Liquidambar</i>	<i>Pinus</i>	Other	Grains counted	Grains used for statistics
0-8 cm	0.0	1.8	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.3	7.1	163	151
8-15 cm	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.6	8.1	155	142
22-30 cm	0.0	1.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.0	12.5	164	144
38-45 cm	0.0	0.0	1.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.8	18.1	182	149
53-61 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.9	12.7	224	196
69-77 cm	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.9	15.4	274	232
84-92 cm	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.4	7.0	194	180
99-107 cm	0.0	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6	13.5	199	172
114-122 cm	0.0	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.7	14.7	187	160
130-138 cm	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.8	11.9	211	186
145-153 cm	0.0	0.0	1.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.9	8.2	161	148
160-168 cm	0.0	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	17.1	8.3	181	166
175-183 cm	0.0	0.5	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.9	9.9	186	168
190-198 cm	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.7	10.9	205	183
205-213 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.2	14.2	169	145
221-229 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	11.5	178	158
226-242 cm	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.7	7.2	176	163
251-259 cm	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.6	10.1	159	143
266-272 cm	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.7	11.4	175	155
282-290 cm	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.5	11.8	164	145
297-305 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.7	9.7	166	150
312-320 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	18.3	5.1	164	156
320-328 cm	0.0	0.6	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15.4	5.7	156	147
335-343 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	36.0	2.4	203	198
351-359 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.1	1.7	285	280
366-374 cm	0.0	0.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	46.6	3.9	193	185
381-389 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	38.0	9.5	158	143
398-397 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	29.0	11.1	169	150

Table 5.—Pollen frequency data for core 9411-7.

Sample depth	<i>Rhizophora</i> Red Mangrove	<i>Avicennia</i> Black Mangrove	<i>Laguncularia</i> White Mangrove	<i>Conocarpus</i> Buttonwood	<i>Batis</i> Saltwort	Chenopods	Gramineae Grass family	Cyperaceae Sawgrass family	<i>Typha</i> Cattail	<i>Nymphaea</i> Water Lilly	<i>Sagittaria</i> Arrowhead
10 cm	24.3	1.9	1.3	4.2	0.3	51.8	0.6	1.9	1.3	0.0	1.3
21 cm	24.4	1.7	0.4	1.2	0.0	31.8	0.4	1.2	0.0	0.8	0.4
35 cm	15.1	5.8	1.2	5.8	0.6	33.1	3.5	2.9	3.5	0.0	1.7
46 cm	31.3	7.5	0.0	1.5	0.0	29.9	3.7	0.0	0.0	0.0	0.7
58 cm	37.9	2.1	0.7	2.8	0.0	32.4	2.1	0.7	0.0	0.0	0.0
69 cm	41.1	3.1	1.2	1.2	0.0	25.8	2.5	2.5	0.0	0.0	0.0
79 cm	34.8	6.8	7.6	2.3	0.0	12.9	1.5	0.8	0.0	0.0	0.0
90 cm	9.3	10.1	0.8	1.6	0.8	25.6	1.6	0.8	0.0	0.0	0.8
104 cm	17.4	15.2	2.2	0.0	0.7	15.9	0.0	4.3	0.0	0.0	0.0
120 cm	1.9	16.3	0.0	1.3	1.3	11.3	6.3	6.3	0.0	0.0	0.0
130 cm	22.3	10.3	1.1	1.7	1.1	8.0	2.3	1.1	0.0	0.0	0.0
145 cm	28.0	8.4	2.8	4.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
155 cm	24.6	8.4	1.7	1.1	0.0	5.6	1.1	1.1	0.0	0.0	0.0
165 cm	26.9	5.4	2.7	1.1	0.5	9.7	0.5	1.1	0.0	0.0	0.0
188 cm	29.3	0.0	0.7	4.1	0.0	0.0	0.0	0.0	2.0	0.0	0.0
205 cm	19.7	0.0	0.0	0.0	1.1	22.5	4.5	2.2	1.7	0.6	1.7
248 cm	5.1	0.0	1.3	0.0	0.0	3.8	3.8	11.5	0.0	4.5	3.8

Sample depth	Umbelliferae Celery family	<i>Utricularia</i> Bladderwort	Compositae	Polygonaceae Smart weed	<i>Ilex</i> Holly	<i>Salix</i> Willow	<i>Morus</i>	<i>Ficus</i>	Triporates
10 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0
21 cm	0.4	0.0	1.2	0.0	0.0	0.0	0.8	0.0	2.1
35 cm	0.0	0.0	0.0	0.6	0.0	0.6	0.0	0.0	1.2
46 cm	0.7	0.0	0.7	0.0	0.0	0.0	0.7	0.0	0.7
58 cm	0.0	0.7	0.0	0.7	0.0	0.0	0.0	0.0	0.7
69 cm	0.0	0.0	1.2	0.0	0.0	0.0	0.0	0.0	1.2
79 cm	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0
90 cm	0.0	0.0	2.3	0.0	2.3	0.8	0.0	0.0	2.3
104 cm	0.0	0.0	2.2	0.0	0.0	1.4	1.4	0.0	2.9
120 cm	0.0	0.0	6.3	0.6	0.0	4.4	0.0	0.0	0.6
130 cm	0.0	0.0	1.1	0.0	0.6	1.1	0.0	0.0	4.0
145 cm	0.0	0.0	0.0	1.4	0.7	0.0	0.0	0.0	0.0
155 cm	0.0	0.0	0.6	0.0	0.0	0.0	0.6	0.0	0.0
165 cm	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0	0.0
188 cm	0.0	1.4	2.0	0.0	0.0	0.0	0.0	0.0	0.7
205 cm	0.0	0.0	1.7	0.6	0.0	0.6	0.0	0.0	2.2
248 cm	0.0	0.0	12.7	0.0	0.6	0.0	0.0	0.0	1.9

for the same core. Discriminant analysis using the surface pollen zonation is a sensitive enough measure to differentiate generally between the mangrove-dominated assemblages that are prevalent in the core. The assignment of core intervals between 328 cm and 190 cm to a mixture of mangrove swamp surface clusters (Text-fig. 9) is expected during the early stages of coastal transgression when variability in substrate type, hydroperiod, elevation, and varying proximity to brackish and freshwater marsh communities would contribute a variety of taxa to the sediment record. The upper 190 cm of core (essentially the last 2,800 years; Text-fig. 9) is assigned almost exclusively to mangrove swamp surface cluster 2, or that cluster represented by the coastal mangrove physiographic province, the de-

position site of the core. This suggests that essentially modern conditions existed in the vicinity of the Harney River coastline for the last 2,800 years, a time surface that occurs within the muddy mangrove peat unit and is otherwise indistinguishable.

Discriminant analysis of core 9411-7 with the surface pollen data set indicates a predominantly mangrove coastal environment of deposition for the core. However, core 9411-7 has been interpreted by Gelsanliter (1996) to contain sedimentologic evidence that suggests a short-lived, high-frequency sea-level oscillation occurred in the overall transgressive sequence at approximately 2,400 ybp. Sedimentologic evidence for this sea-level oscillation first occurs in the form of *Rhizophora* peats prograding over subtidal marine car-

Table 5.—Continued.

Sample depth	<i>Cephalanthus</i>	<i>Fraxinus</i>	Sapotaceae	<i>Quercus</i> Oak	<i>Anacardium</i>	Tricolpates	<i>Alnus</i> Alder	<i>Carya</i>	<i>Pinus</i>	<i>Taxodium</i> Cypress
10 cm	0.0	0.0	0.0	0.3	0.0	1.0	0.0	0.0	2.9	1.0
21 cm	0.0	0.0	0.4	0.0	0.0	0.8	0.0	0.4	2.5	3.3
35 cm	0.6	0.0	0.0	0.0	0.0	1.7	0.0	0.0	4.7	5.8
46 cm	0.0	0.0	1.5	0.0	0.0	0.0	0.7	0.0	2.2	1.5
58 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.8	2.1
69 cm	0.0	0.0	0.0	0.0	0.0	0.6	0.0	0.0	3.7	0.6
79 cm	0.0	0.0	0.8	3.0	0.0	1.5	0.0	0.0	1.5	0.0
90 cm	0.0	0.0	0.0	0.0	0.8	1.6	0.0	0.0	6.2	0.0
104 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.6	0.0
120 cm	0.6	0.0	0.0	0.0	0.6	0.6	0.0	0.0	6.3	0.0
130 cm	1.1	0.0	0.0	0.0	0.0	2.9	0.0	0.0	15.4	0.0
145 cm	0.7	0.7	0.0	0.0	0.0	0.0	0.0	0.0	24.5	0.0
155 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	28.5	1.1
165 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	25.3	0.0
188 cm	0.0	1.4	0.0	0.0	0.0	0.0	0.0	0.0	15.6	2.0
205 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	5.6	0.0
248 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.1	0.0

Sample depth	Monocolpates	<i>Vitis</i> Grape	Inaperturate	cf. <i>Ovoidites</i>	<i>Polygala</i> Milkwort	<i>Osmunda</i>	<i>Polypodium</i>	Others and unidentified	Grains counted	Grains used for statistics
10 cm	0.0	0.0	0.6	0.6	0.0	0.0	0.3	4.9	306	294
21 cm	0.0	0.4	2.1	0.0	0.0	0.4	1.2	20.7	242	183
35 cm	0.6	0.0	0.0	0.6	0.0	0.0	1.2	18.0	163	152
46 cm	0.0	0.0	2.2	0.0	0.7	0.0	0.0	11.2	122	113
58 cm	0.0	0.0	0.7	0.0	0.0	0.0	0.0	14.5	130	124
69 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.0	145	137
79 cm	0.0	0.0	3.0	1.5	0.0	0.0	0.0	25.8	111	98
90 cm	1.6	0.0	2.3	0.0	0.0	0.0	1.6	27.1	105	87
104 cm	0.0	0.0	0.0	0.0	1.4	0.0	0.0	22.5	111	106
120 cm	0.0	0.0	2.5	0.0	0.0	1.9	4.4	16.3	130	112
130 cm	1.1	0.0	1.7	0.0	0.0	0.6	0.0	33.7	142	126
145 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	52.4	107	102
155 cm	0.0	0.0	1.1	0.0	0.0	0.0	0.0	52.5	140	133
165 cm	0.0	0.0	0.0	0.0	0.0	0.0	0.0	43.5	144	138
188 cm	0.0	0.0	3.4	1.4	0.0	0.0	0.0	48.3	102	89
205 cm	0.0	0.0	2.2	1.7	0.0	1.1	1.1	28.1	130	123
248 cm	0.0	0.0	0.0	2.5	0.0	0.0	0.0	19.1	106	100

bonates (regression) at about 2,800 years before present (Text-fig. 10). This may be the event that stabilized the coastline in core 59-T1. Regression mangrove peats are overlain by marine carbonate mud as the coast is transgressed. From 98 cm to 75 cm is a tan, supratidal carbonate mudstone. This represents a period of rapid sediment reworking following the sea-level oscillation centered around 2,400 ybp (Gelsanliter, 1996). *Rhizophora* peats overlie the sequence to the depositional surface and indicate continual transgression. Discriminant analysis of core samples with the surface pollen data set yields variable results that attest to both the sensitivities and limitations of this method. Sample 248 cm is correctly attributed to the brackish marsh, as the sample is from reworked basal

Holocene quartz sands. Samples 205 cm to 104 cm are all assigned to mangrove swamp cluster 2, representing the coastal margin physiographic province (Text-figs. 7 and 10). Cluster 2 is represented by the widest variety of taxa in the mangrove swamp clusters and is characterized by higher percentages of chenopods and *Avicennia* pollen. These characteristics reflect the fact that the coastal margin mangrove swamp has the most variability in substrate type, hydroperiod, and elevation. It is therefore reasonable that discriminant analysis assigned all of these intervals to cluster 2 regardless of the fact that the host sediments varied from *Rhizophora* peats (both transgressive and regressive) to marine carbonate muds. All these samples shared high overall percentages of *Rhizophora* pollen with

complex mixtures of *Avicennia*, chenopods, *Pinus*, and other taxa, yet all were deposited in close proximity to the coastal margin.

Samples 90 cm and 79 cm were both excluded from discriminant analysis because of low overall pollen sums. This is significant in that both samples come from the tan, supratidal carbonate mudstone that represents a period of rapid sediment reworking and build-up of a supratidal coastal barrier (Gelsanliter, 1996). These intervals undoubtedly have low pollen sums because the pollen signal was inundated by reworked marine sediment. The upper 58 cm of the core sequence are discriminated to cluster 2 (coastal mangrove swamp, 3 samples), cluster 3 (mangrove swamps along the Shark River Slough), and cluster 6 (upper headwater marsh). This sequence represents an overall change upwards to reflect the influence of proximity to brackish and freshwater taxa. Cluster 3 incorporates higher percentages of triporates, chenopods, and *Conocarpus*, while cluster 6 is dominated by chenopods. These discriminant assignments reflect the present proximity of the depositional site to the inner bays and its inclusion in the brackish to transitional marsh physiographic province (Text-fig. 7).

While discriminant analysis of core 9411-7 with the surface pollen data set initially suggests that this technique is not sensitive enough to differentiate significant sedimentologic variability in a core sequence, it does yield predictable results. Discriminant analysis indicates an overall transgression in the core sequence that is present and correctly positions the contemporary depositional environment. The method, however, fails to recognize a sea-level oscillation because it assigns all samples throughout the interval to the coastal mangrove swamp. Undoubtedly, the pollen signature of sediments deposited during this oscillation were, in fact, representative of the coastal mangrove swamp.

CONCLUSIONS

In South Florida, the boundaries between vegetation communities are commonly well defined, but boundaries between pollen zones are blurred because of mixing of pollen by fluvial, tidal, and atmospheric processes. Multivariate statistical techniques provide a sensitive and objective means of delineating the distribution of pollen and spores in the study area.

Cluster analysis of pollen and spore types from surficial deposits in the study area indicates that individual taxa typically are not environmentally restricted and, in most environments, there are no single indicator species because of broadly overlapping geographic ranges. Multivariate analysis of pollen assemblages is required to separate surface sample pollen assemblages into distinct pollen zones. Cluster analysis of pollen and spores from surface sample sites produced five clusters, or pollen zones, containing a total of 10 sub-clusters that help delineate subtle differences within each zone. The spatial distribution of these pollen zones strongly corresponds to the major physiographic provinces of the area. These pollen zones are: 1) mangrove swamp, 2) brackish marsh, 3) freshwater marsh, 4) headwater marsh, and 5) upland complex. The correlation between the spatial distribution of clusters and physiographic provinces in the study area strongly suggests that the surface pollen cluster groupings have environmental meaning and that pollen can provide valuable information for paleoenvironmental reconstructions. Discriminant analysis underscores the distinctiveness of the environmental groupings obtained from cluster analysis. It also supplies the objective criteria and a methodological protocol for accurately assigning group membership to pollen and spore assemblages from vertical stratigraphic sequences and ultimately facilitates paleoecological interpretations. A visual comparison of unknown samples with the 18 key taxa identified herein indicates that the reduced set is also useful in making a first approximation in assigning an unknown sample to a surface pollen zone.

Results from two cores, 59-T1 and 9411-7, indicate the methods used in the study can identify the overall late Holocene transgression of South Florida from pollen assemblages in vertical sequences and can differentiate among different mangrove swamp communities as coastlines are first transgressed and then stabilized. The method is limited in its ability to differentiate short-lived changes in coastal configuration (*i.e.*, sea-level oscillations) as long as the overall environment remains in close proximity to the coastal zone. Detailed sedimentologic work, combined with palynological analysis is required, especially where sediment reworking has occurred.

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CHAPTER 7

A CENTURY OF ENVIRONMENTAL VARIABILITY IN OYSTER BAY USING OSTRACODE ECOLOGICAL AND ISOTOPIC DATA AS PALEOENVIRONMENTAL TOOLS

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ABSTRACT

Stable isotopic analysis ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) and characterization of the ostracode community structure were carried out from a high-resolution sediment-core recovered from Oyster Bay in the west of the Everglades National Park. Because of its location, between the Shark River Slough (SRS) and the Gulf of Mexico, the Oyster Bay core locality experiences extreme salinity fluctuations due to the interaction of freshwater run-off, precipitation, and marine water inputs. Ostracode population dynamics and isotopic variability over the 20th century are linked to natural and anthropogenic forces that affect the South Florida coastal ecosystem on interannual to decadal time scales. Three ostracode assemblages can be recognized within the 100-year sediment-core record: the first extending from the turn of the century to about 1950; the second, from the early 1950s to the late 1970s; and the third to core recovery in 1995.

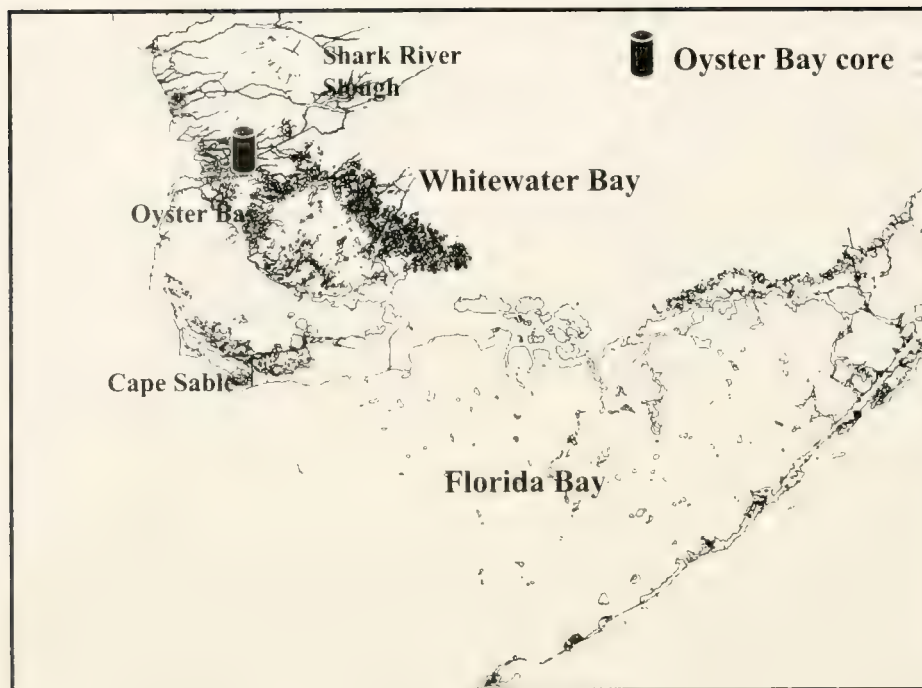
An abrupt decrease in ostracode abundance, species diversity, and shifts in species dominance occur in the mid-1980s and reflect episodes of environmental stress. Markedly enriched $\delta^{18}\text{O}$ values from the ostracode *Peratocytheridea setipunctata* and the benthic foraminifer *Ammonia parkinsoniana typica* at this time are concurrent with a major regional drought in South Florida, as well as with documented algal blooms and major die-off of sea grasses in Florida Bay. In addition, the timing of these events is contemporaneous to the onset of the South Florida Water Management District (SFWMD) "Rainfall Plan" and the closing of the Buttonwood canal. Higher ostracode abundance and species richness occurs between the late-1950s and late-1970s. Stable isotopic data and ostracode assemblage characteristics suggest a period of relative environmental stability and possibly improved water circulation in Whitewater Bay and Oyster Bay. Fluctuations in community structure during this time are more systematic and appear to be temporally correlated to rainfall variability patterns. Water management policies at this time are also discernable from the microfaunal and isotopic record, particularly the Congressionally mandated Monthly Minimum Allocation Plan of water supply to SRS. Before 1950, hurricane events and their effects are the major cause for immediate modifications within the ostracode community, though our data show that ostracode populations are capable of rapid recovery. Over the complete record of the last century, the effects of water management practices can be assessed from information embedded in the ostracode record. Nevertheless, the effects of natural climatic variability in Oyster Bay appear to outweigh the impact of anthropogenic forces.

INTRODUCTION

Over the past decade, scientists have used proxy records of environmental conditions in Florida Bay and its environs to examine the paleoecological history of this region (Brewster-Wingard *et al.*, 2000; Halley and Roulier, 1999; Swart *et al.*, 1996, 1999; Nelsen *et al.*, in press). Benthic microfaunal communities preserved in undisturbed sediment records have shown great promise for the reconstruction of paleoenvironmental fluctuations (Alvarez Zarikian *et al.*, 1999a, 1999b; Brewster-Wingard and Ishman, 1999; Cronin *et al.*, 2000; Dwyer and Cronin, 2000; Hood *et al.*, 1998; Ishman, 2000). Ostracodes have proven particularly valuable for such reconstructions because they are abundant in the marine and brackish water environments of South Florida (Puri and Hulings, 1957; Puri, 1960; Benda and Puri, 1962; Keyser, 1975, 1977). In addition, they have specific ecological requirements

and well defined salinity tolerances (Neal, 1988). Moreover, ostracodes rapidly secrete a calcitic bivalve shell (Turpen and Angell, 1971), which with genetic influences, records the isotopic composition of the aquatic environment, thus providing a geochemical snapshot of the chemical conditions of the water in which they lived.

The lower Everglades National Park is comprised of a north-south ecosystem succession ranging from large flat wetlands in the north to shallow bays, lakes and channels in the south, which are mostly filled with mangrove swamp deposits and bordered by mangrove forests. The environmental transition into the coastal zone is gradual and it extends into the shallow mud-banks and semi-restricted basins of Florida Bay. To the west and north of Cape Sable, the 1–2 meter-deep Whitewater Bay extends to the northwest through the mangrove forest and Oyster Bay until opening up to



Text-figure 1.—Location Map of Oyster and Florida Bays. Sediment core location in Oyster Bay represented by black cylinder.

the Gulf of Mexico. Direct freshwater runoff from the Everglades into Florida Bay and adjacent bays is primarily through the natural drainage basins of Shark River and Taylor Sloughs, and artificially from the C-111 Canal. To the west, the park is heavily influenced by the marine waters of the Gulf. Freshwater input from canals and watersheds that flow into Florida Bay is strongly influenced by rainfall and freshwater management policies of the South Florida Water Management District (Nelsen *et al.*, in press; Rudnick *et al.*, 1999).

Numerous hydrological modifications have impacted the Everglades natural ecosystem during the 20th century. Among these are the fragmentation of the wetlands due to construction of a massive network of canals and levees for water supply and flood control, and the loss of extensive wetland area to agriculture and residential development (Davis and Ogden, 1994). Prior to human impact, natural forces and seasonal climatic variability were the main factors controlling hydrological conditions in the area. Increased salinity and nutrient concentration in Florida Bay (McIvor *et al.*, 1994), as well as algal blooms and major seagrass die-offs (Fourqurean and Robblee, 1999; Robblee *et al.*, 1991), have raised growing concerns as to whether the origin of these changes are anthropogenic or are part of a natural cycle of climatic variability.

Micropaleontological and stable isotopic data obtained from a high deposition rate sediment-core col-

lected in Oyster Bay are presented here. These data have allowed interpretation of interannual to decadal changes in hydrological conditions from this area within the Everglades National Park. Because of its location, adjacent to Shark River and the Gulf of Mexico, the Oyster Bay core locality experiences extreme salinity fluctuations (4 to >40 parts of salinity, Boyer *et al.*, 1997) due to the interaction of freshwater runoff, precipitation and marine water inputs. Because of the wide range of environmental conditions, this site is ideally located to examine the response and sensitivity of ostracode populations and their isotopic composition to environmental change over the last century.

CORE SELECTION AND GEOCHRONOLOGY

An undisturbed sediment record is a pre-requisite for the meaningful interpretation and reconstruction of paleoenvironmental changes. The Oyster Bay core (Text-fig. 1) used in this study is one of many collected in Florida and adjacent bays during the last four years. It was recovered from seagrass-free soft bottom sediments in shallow water (1 m). This high sedimentation rate core has been the focus of an interdisciplinary study to reconstruct Oyster Bay's paleoenvironmental record. Analyses that have been completed include microfossils and pollen assemblage, stable isotope, organic and inorganic carbon, mineralogy and heavy metals (Nelsen *et al.*, in press).

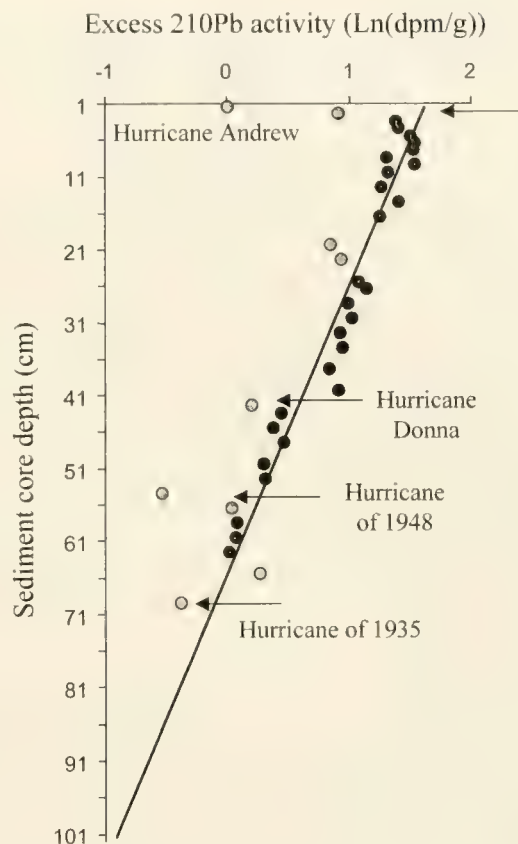
The location of the sediment core was carefully tar-

geted from review of sequential aerial photographs (1927–present) and published data on the dynamics of banks and deltas in Florida Bay (Wanless and Tagett, 1989). Aerial photographs helped identify sites that had been free of macro vegetation since the time of the earliest aerial photograph. Subsequent reconnaissance coring sought to verify that the site was an area of active sediment accumulation and that it had well-preserved stratification (minimal bioturbation activity) (Nelsen *et al.*, in press).

The 1.5-m long Oyster Bay core was examined for stratification/disruption utilizing X-radiography to assure that sediment geochronology would yield interpretable sequences. Stratification in the sediment core was clear, with laminations consisting of alternations of mangrove organics, carbonate silt, and fine quartz. The core was age-dated using the ^{210}Pb -dating technique (Nelsen *et al.*, in press), described, and photographed for evaluation of sediment type and structures. The sediment accumulation rates derived from the profile of excess ^{210}Pb were approximately 1.1 cm/yr (0.6 g/cm²/yr). The geochronology for the Oyster Bay core was extended back to the turn of the century by extrapolating the activity of excess ^{210}Pb downcore. In addition to providing a time-line and accumulation rate information, fine-structural features were observed in the excess ^{210}Pb profile including sediment erosion/deposition bands that are tied by year to hurricane events. These discontinuities appear as lower levels of excess ^{210}Pb than would be expected from the overall trend. These lower levels are most likely a result of the combined effects of losing sediment from the core site during a storm and input of sediments with lower levels of excess ^{210}Pb , *i.e.*, older sediments or organic-rich debris, from upland or other sources (Nelsen *et al.*, in press). In the Oyster Bay core site, sudden shifts in the ^{210}Pb activity correspond (within ± 3 years) to the years of 1960, 1948, and 1935 (Text-fig. 2) and are likely the result of sediment movement due to Hurricane Donna, the hurricane of 1948, and the Great Labor Day Hurricane in 1935, respectively.

Given the established age model, the Oyster Bay core was subsampled at 1-cm intervals for geochemical (organic carbon, heavy metals, stable isotopes), micropaleontological (ostracodes and benthic foraminifers) and palynological characterization. These data were complemented by an analysis of historical rainfall, gauged freshwater flow, and limited near shore salinity data (see Nelsen *et al.*, in press).

It is important to note that geochronology-based ages have associated error estimates that increase downcore. As a result, ^{210}Pb -derived core ages in the 1940s and 1920s, for example, have a range of ± 3 and ± 4 years at the core location in Oyster Bay. For more recent



Text-figure 2.—Excess ^{210}Pb profile used to establish the geochronology for the Oyster Bay core (from Nelsen *et al.*, in press).

years, between 1980 and 1995, sediment geochronology varies by only ± 1 year (Nelsen *et al.*, in press).

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would like to thank Dr. Larry Peterson for reviewing the manuscript and for his helpful suggestions.

METHODS

MICROFAUNAL ANALYSIS

Core sediment intervals were sub-sampled, wet-sieved using a 63 μm mesh, and the coarse fraction retained for microfaunal characterization. High organic content in the Oyster Bay core required the use of ashing and 30% hydrogen peroxide treatments. Sub-sample weights were used to determine total population abundances expressed as tests or valves per gram dry sediment weight. A minimum of three hundred specimens of both ostracodes and foraminifers were counted for each sample unless limited by sample size.

Temporal fluctuations in microfaunal community structure were evaluated using relative and absolute abundances, and the Shannon-Weiner diversity index (SWDI). The SWDI is defined as: $H = -\sum_{i=1}^N p(i) \ln p(i)$, where H is the measure of diversity, N is the number of species counted and $p(i)$ is the proportion of the total number of individuals which belong to the i^{th} species (MacArthur, 1983). This index incorporates a measure of species evenness as well as number (communities with many species with equal-size populations have the highest index) (Patrick, 1983), making it sensitive to the presence of rare species.

STABLE ISOTOPE ANALYSIS

Stable isotopic analyses ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) were carried out on valves of the ostracode *Peratocytheridea setipunctata*. This species was chosen for isotopic analysis due to its ubiquitous occurrence throughout the Oyster Bay core as well as its high abundance in surface sediment samples collected from Oyster and Whitewater bays and Florida Bay. Well-preserved adult valves of *P. setipunctata* were isolated from the $>63 \mu\text{m}$ sediment fraction prior to the ashing/ H_2O_2 treatments. Specimens were cleaned with a small paintbrush in a distilled water bath and then in an ethanol solution to remove adhering debris. Between 6 to 8 valves of *P. setipunctata* were then immersed in methanol-filled "copper boats" and crushed to a powder. The carbonate samples were processed by an automated device attached to a Finnigan-MAT 251 mass spectrometer. The external precision (0.02‰ for $\delta^{13}\text{C}$ and 0.08‰ for $\delta^{18}\text{O}$) was calculated from replicate analyses of the RSMAS Stable Isotope Laboratory calcite standard. All isotopic data are reported in per mil (‰) units relative to the Pee Dee Belemnite (PDB) standard and are corrected for the usual isobaric interferences. The stable isotopic composition of the sediment's organic C fraction was analyzed as well (Nelsen *et al.*, in press).

RAINFALL AND FRESH WATER FLOW DATA

Continuous monthly freshwater flow data for Shark River Slough extending from 1939 to the present were obtained from the United States Geological Survey (<http://fl.water.usgs.gov/>). Rainfall data were obtained from NOAA's National Climate Data Center. Continuous monthly data from the Everglades, Flamingo, Homestead and Tavernier stations were obtained, extending from present back to 1926, 1951, 1911, and 1936, respectively (Nelsen *et al.*, in press).

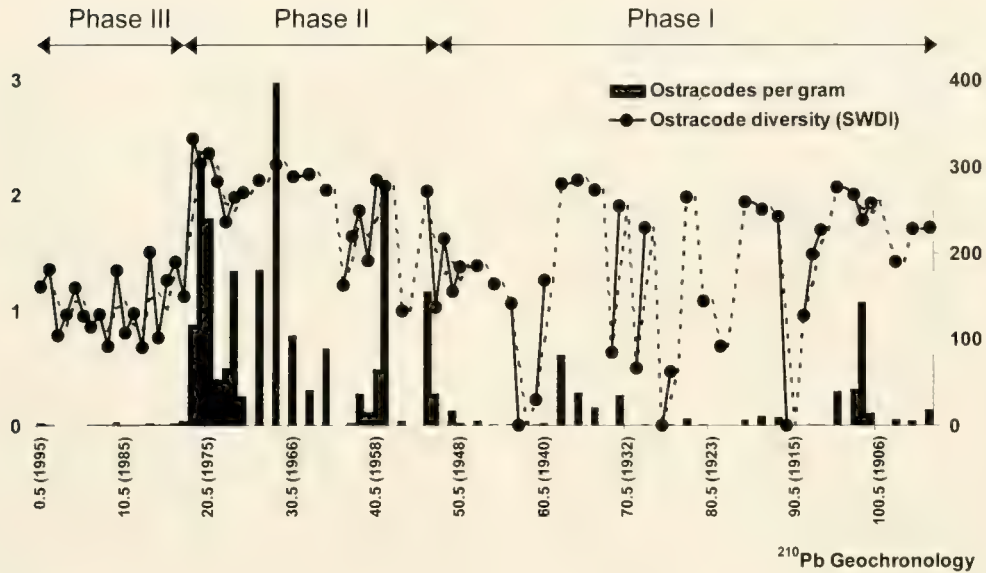
RESULTS

The three major sediment components in the Oyster Bay core are carbonates, alumino-silicates and organic matter. The average CaCO_3 content is $75 \pm 5\%$ and is comprised mostly of benthic foraminifers, ostracodes, small mollusks and calcareous fragments. The organic C content averages $7.1 \pm 1.3\%$, while the alumino-silicate contribution is minor, averaging only $1.6 \pm 0.3\%$ (Nelsen *et al.*, in press).

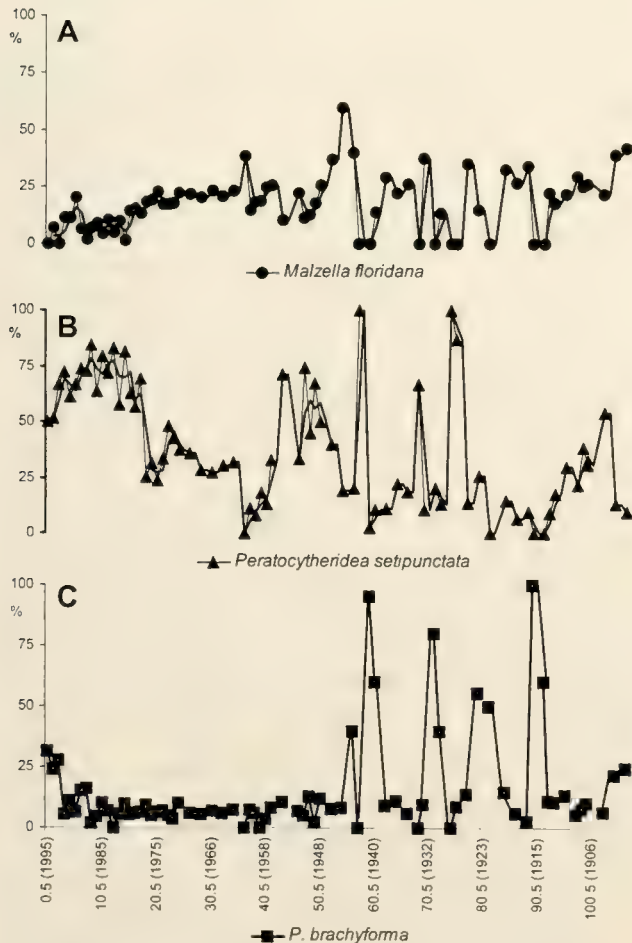
OSTRACODE ASSEMBLAGE

The Oyster Bay core contained 43 ostracode species. The number of species in any one sample ranged from 2 to 27, with an average of 11 species per 1-cm sample. Ostracode diversity, total abundance and species evenness show large temporal fluctuations (Text-fig. 3). Significant variability in species dominance and temporal loss of numerous species towards the present time also occurred. In addition, microfaunal preservation is lower towards the top of the core.

The Shannon-Weiner diversity index (SWDI), used here to express ostracode diversity, is sensitive to the presence and absence of minor species, such that larger positive values reflect greater diversity while lower numbers indicate a community dominated by fewer species. The SWDI ranged from 0.22 at a depth of 18.5 cm (~ 1977) to 2.51 at a depth of 59.5 cm (~ 1941). Ostracode abundance in the sediment core ranged from 0 to 397 valves per gram. Highest ostracode abundance and diversity occurred in sediments deposited in the mid-1970s, and in the late-1960s and 1950s. In contrast, the bottom half of the core, recording deposition between the turn of the century and the late-1940s, is characterized by a fairly diverse and stable community and a relatively low ostracode abundance (Text-fig. 3). The lowest abundances were found in sample intervals at 90, 74 and 57 centimeters. These samples contained less than 10 ostracode valves each, mainly of *Perissocytheridea brachyforma*, and represent the years of 1915 ± 4 , 1929 ± 4 and 1941 ± 3 , according to the extended ^{210}Pb -derived geochronology. The timing of two of these events temporally correlates with hurricanes that occurred over areas of



Text-figure 3.—Ostracode diversity (Shannon-Weiner diversity index; left axis) and abundance (valves/g; right axis) in the Oyster Bay core. Geochronology based on ^{210}Pb and ^{137}Cs dating techniques (cm (year)).



Text-figure 4.—Relative abundances of: a) *Malzella floridana*; b) *Peratocytheridea setipunctata*, and c) *Peratocytheridea brachyforma* in the Oyster Bay core. X-axis: ^{210}Pb geochronology (cm (year)).

Florida Bay: the Hurricane of 1929, and the Great Labor Day Hurricane of 1935.

From 1956 ± 2 to 1977 ± 1 , the ostracode assemblage at this location exhibited high abundance and species diversity indicating a stable and robust ostracode community. Population evenness was relatively high and constant at this time. Following this long, stable interval, in about 1978 ± 1 , a dramatic decline in assemblage diversity occurred (Text-fig. 3). The SWDI was reduced by half (from ~ 2 to ~ 1) and ostracode abundance dramatically declined from more than 300 ostracodes per gram to less than 50. This marked the second long-term decline in ostracode community structure during the 20th century. The number of species dropped from an average of 18 species per sample to less than five and the ostracode assemblage became dominated by *Peratocytheridea setipunctata* (Text-fig. 4b). However, despite its high relative abundance, *P. setipunctata* displays low absolute abundance which suggests survivor type dominance rather than opportunistic behavior. SWDI and evenness increase slightly at the top of the core, although, ostracode abundance remains low.

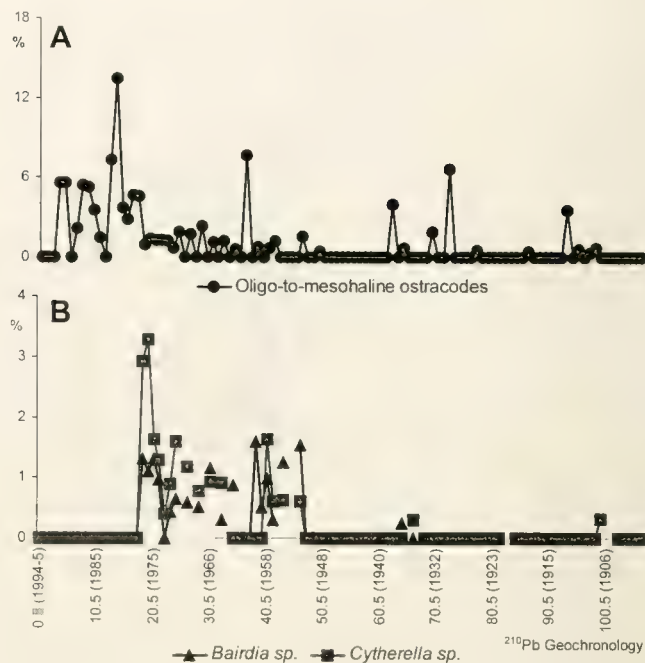
The most common ostracode species in the core were *Peratocytheridea setipunctata*, *Malzella floridana*, *Neocaudites triplistriatus* and *Perissocytheridea brachyforma* with maximum absolute abundances of 113, 80, 71 and 22 valves per gram, respectively. *Actinocythereis subquadrata*, *Loxoconcha matagordensis* and *Xestoleberis mixohalina* were also common throughout the core, but their relative abundances never exceed 15% of the total assemblage at any particular



Text-figure 5.—Relative abundances of a) *Neocaudites triplistriatus*; b) *Actinocythereis subquadrata*; and c) epiphytic ostracode species *Loxoconcha matagordensis* in the Oyster Bay core. X-axis: ^{210}Pb geochronology (cm (year))

sediment interval. Inter-specific dominance among *P. setipunctata*, *M. floridana*, *N. triplistriatus* and *P. brachyforma* has changed through time (Text-fig. 4a,b,c; and Text-fig. 5a). The ostracode *Peratocytheridea setipunctata* showed a marked increase in relative abundance in about the late 1970s and remained the dominant species (>50%) well into the mid-1990s. In contrast, the relative abundance of *Malzella floridana* remains rather constant throughout the core, exhibiting a peak in abundance in the mid-1940s, and a decline during the 1980s. Although *P. setipunctata* and *M. floridana* are the two most common species in the Oyster Bay core, their relative abundance appears to be inversely correlated ($r = -0.72$).

In the other hand, the mesohaline species *Perissocytheridea brachyforma* is found sporadically in the lower portion of the Oyster Bay core in abundances of up to 50%. This corresponds to the time before 1950. Since then, abundance of *P. brachyforma* re-

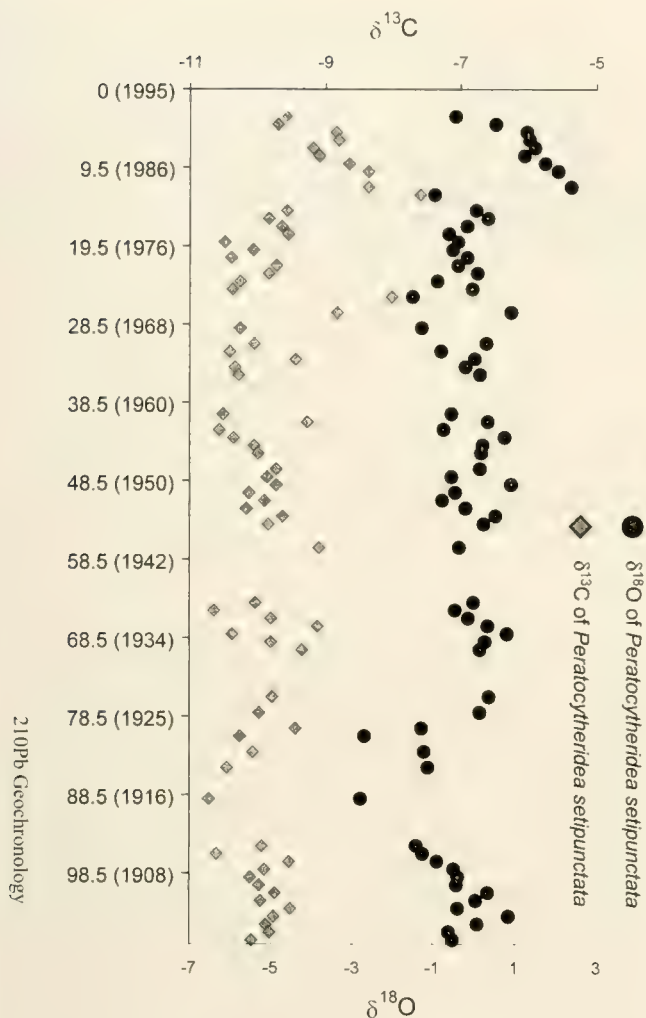


Text-figure 6.—Relative abundance of: a) Grouped oligohaline and β -mesohaline species: *Candona* sp., *Cypridopsis okeechobei*, *Cytheridella illosvayi*, *Darwinula stephensoni*, *Limnocythere floridensis* and *Physocypria* sp. A; and b) Euhaline species: *Bairdia* sp. and *Cytherella* sp. in the Oyster Bay core. X-axis: ^{210}Pb geochronology (cm (year))

mained generally low until the early 1990s when its relative abundance increased again reaching 25% of the total ostracod assemblage. On the contrary, *Neocaudites triplistriatus* exhibited its greatest abundance just before *P. brachyforma* in the early 1910s (>40%), and at about 1960 (~50%). Although present to some extent throughout the core, *N. triplistriatus* has been essentially absent from the Oyster Bay core since early in the 1980s (Text-fig. 5a).

A group of oligo-mesohaline species, such as, *Candona* sp., *Cypridopsis okeechobei*, *Cytheridella illosvayi*, *Darwinula stephensoni*, *Dolerocypria fastigata*, *Limnocythere floridensis* and *Physocypria* sp. occurred at sporadic intervals in the sediment core corresponding to the mid-1910s, early 1930s, early 1960s, early 1980s, and in the early-1990s (Text-fig. 6a). *Cypridopsis okeechobei*, *Cytheridella illosvayi* and *Darwinula stephensoni* are the most common species of this group, reaching in some intervals over 7% of the total ostracode assemblage.

In contrast, euhaline species such as *Bairdia* sp. and *Cytherella* sp. are only present in the Oyster Bay core at lower percentages (<4%). Although less significant in number, their distribution is clearly limited to the period of highest diversity and population abundance that occurred between the early 1950s and late 1970s



Text-figure 7.—Stable isotopic composition ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) of the ostracode species *Peratocytheridea setipunctata* in the Oyster Bay core.

(Text-fig. 6b). A gap in the occurrence of euhaline species is visible around 1960.

The $\delta^{18}\text{O}$ isotopic composition of the ostracode *Peratocytheridea setipunctata* ranged from -2.80 to $+2.37\text{‰}$. Strong negative excursions are found prior to 1925 ± 4 , while the most positive values occurred during the 1980s (Text-fig. 7). Between the early 1950s and 1970s, the $\delta^{18}\text{O}$ values do not show large deviations. During this time, values oscillate between -1 and $+1\text{‰}$ on time scales of 1 to 3 years.

The $\delta^{13}\text{C}$ of *Peratocytheridea setipunctata* at Oyster Bay exhibits very negative values, ranging from -7.59 to -10.72 . Relatively constant and lighter values (approximately -10‰) occur between early 1900s and late 1950s. Isotopic trends during this time are gradual, trending to more positive or negative values in roughly decadal timescales. In contrast, abrupt positive shifts

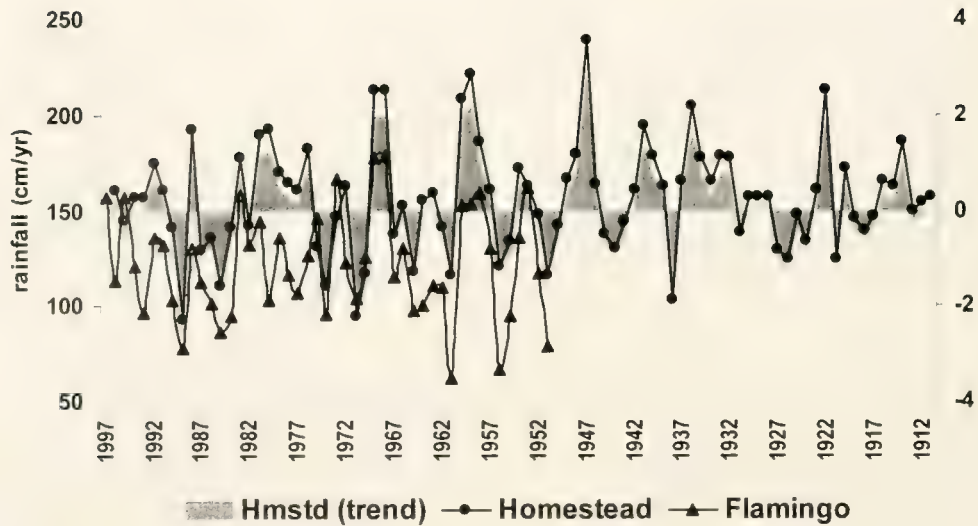
in the $\delta^{13}\text{C}$ record take place at about 1970 ± 1 and 1983 ± 1 . The $\delta^{13}\text{C}$ of *P. setipunctata* at these times is enriched by more than 2‰ . An increase in the magnitude of fluctuations of the $\delta^{13}\text{C}$ is evident upcore.

DISCUSSION

MICROFAUNAL RESPONSE

Large decreases in ostracode abundance and diversity and shifts in species dominance that occurred in the Oyster Bay core represent episodes of environmental stress due to natural and/or anthropogenic forces. Distinctive characteristics of the ostracode assemblages from the core locality were used to divide the 100-year ostracode record into three zones. The first zone extends from the turn of the century to about 1950; the second, from the early 1950s to the late 1970s; and the third to the time of core recovery in 1995. Before 1950, the significant declines in ostracode community structure that occurred in 1915 ± 4 , 1929 ± 4 , 1941 ± 3 and 1948 ± 2 are temporally coincident with severe tropical storms or hurricanes: the tropical storm of 1916, the hurricane of 1929, the Great Labor Day hurricane in 1935, and the hurricane of 1948. Hurricanes are capable of causing immediate or long-term environmental changes in coastal areas due to sediment erosion and deposition, and storm induced bi-directional sediment transport (Tabb and Jones, 1962; Smith *et al.*, 1994; Wanless *et al.*, 1994). Decline in the ostracode populations and the input of reworked freshwater species as seen in the Oyster Bay core are evidence of hurricane disturbance. However, according to our data, reasonably rapid population recoveries from these events indicate a relatively resilient community. The first zone culminated with a decade-long diversity low, and an ostracode assemblage dominated initially by *Malzella floridana* and later by *Peratocytheridea setipunctata*. Rainfall data from the Homestead station (Nelsen *et al.*, in press) showed lower than average rainfall during the early 1940s, with a later increase in rainfall from the mid to late 1940s (Text-fig. 8). In contrast, freshwater flow data for Shark River Slough during that time shows a diminished flow during most of the 1940s (Nelsen *et al.*, in press). The Homestead rainfall data are used as a comparison in this case because the record is longer (back to 1911) than that of the Flamingo meteorological station, whose data only extend from 1951 to the present.

The second zone, between the late 1950s and late 1970s, exhibited the richest ostracode fauna (average: >200 valves/g) and the highest diversity (SWDI >2). Community fluctuations during this interval are more gradual and can be temporally correlated to SFWMD policies. The second zone generally represents a "bloom" period interrupted only by a brief hiatus in



Text-figure 8.—Rainfall record during the 20th century from the Flamingo and Homestead meteorological stations (NOAA's National Climate Data Center). Gray area: trend analysis for Homestead rainfall station (right axis).

the ostracode assemblage continuity about 1960, coincident with Hurricane Donna. During this period major construction also occurred (1960–63) with vast areas of the Everglades north of Tamiami Trail delimited with new levees and canals. Water flow into the Shark River Slough (SRS) at this time, began to be controlled by a series of gate spillways in order to create the current system of Water Conservation areas (Light and Dinnen, 1994). In addition, higher concentrations of organic carbon in the sediment intervals of this period, and at about 1935 (Nelsen *et al.*, in press), support the hypothesis of hurricane effects. Large amounts of organics derived from sediment transport and subsequent settling of suspended material occurred at this time. Oxidation of high concentrations of organic material at the sediment/water interface may have reduced oxygen levels, temporarily inhibiting occupation by most of the benthic microfaunal assemblage.

During the late 1950s through late 1970s, small numbers of the euhaline ostracodes *Bairdia* sp. and *Cytherella* sp. also appeared (up to 4%, see Text-fig. 6b). Typical marine species were not present in relative abundances greater than 0.3% anywhere in the core until this time. Two reasons potentially explain the appearance of euhaline taxa at the core locality. First, hurricane-related onshore sediment transport due to the Hurricane of 1948 and Hurricane Donna (1960). Second, less than average rainfall in the area during the 1950s may have favored marine water input from the Gulf of Mexico, allowing shelf taxa to adapt to the otherwise brackish waters of Oyster and Whitewater bays. Between the 1960s and early 80s, the SFWMD implemented a series of short-term water management plans (1963–70), and more importantly the congressionally

mandated Monthly Minimum Allocation Plan of water supply to SRS (Light and Dineen, 1994). The latter practice resulted in essentially, no correlation between rainfall and flow ($r = -0.06$) (Nelsen *et al.*, in press). The time interval encompassed in zone 2 was also temporally coincident with the opening and closing of the Buttonwood Canal (late-1950s and late-1970s). The Buttonwood Canal may have led to improved water exchange between Florida Bay, Whitewater Bay and the Gulf of Mexico by means of tidal water movements, ultimately improving water quality in Whitewater Bay. The second ostracode zone ended circa 1979, when an abrupt decline in population diversity and abundance occurred, from which the ostracode assemblage had not yet fully recovered as of 1995.

The third zone extends from about 1979 until 1995 when the sediment core was taken. It is highlighted by a large decline in ostracode diversity and abundance at about 1980 and the survivor-mode dominance exhibited by *Peratocytheridea setipunctata*, one of the two most common species in the core, known to be tolerant to extreme salinity fluctuations (<5 to 42) (Keyser, 1977; pers. comm., 1999). The early 1980s marked the end of the SFWMD's Monthly Minimum Water Delivery Plan, which was replaced by a regulated flow plan believed to be more natural, known as the Rainfall Plan. In addition, a great part of the natural flow of freshwater running through Shark River Slough was deviated into the drainage basin of Taylor Slough. This cutback in freshwater renovation is likely to have induced strong evaporative conditions in Oyster Bay at this time. Natural climatic variability (the mid-1980s drought in South Florida) appears to have further impacted environmental conditions and prob-

ably outweigh the impact of anthropogenic forces in this time period. Extracting information embedded in the ostracode record to assess and isolate the effects of water management practices may then, not be easy in this case. The modest presence of the oligohaline species *Cypridopsis vidua*, *Cytheridella illosvayi*, *Darwinula stephensoni* (7, 3 and 7% respectively) in the early 1980s is considered the result of sediment transport.

INTERPRETATION OF STABLE ISOTOPIC COMPOSITION

Stable isotopic analysis of coastal ostracodes is not routine and it is fraught with many complexities as such studies are still in an early stage. Freshwater and deep sea ostracodes are comparatively simpler than in coastal taxa because variations in salinity and temperature in those environments are relatively small and require the understanding of control by only a few parameters (*i.e.*, ice volume). Coastal species are controlled by many other environmental parameters (*i.e.*, rainfall, evaporation) that have the potential to change dramatically in a seasonal basis. Therefore, the understanding of the interaction between these processes and the isotopic composition of ostracode valves is not straightforward, but we will attempt to demonstrate the feasibility of such studies in paleoenvironmental reconstruction of coastal ecosystems.

The ubiquitous occurrence of *Peratocytheridea setipunctata* made this species ideal for an evaluation of the utility of stable isotopic analysis as a paleoenvironmental tool. The stable isotopic composition ($\delta^{18}\text{O}$ and $\delta^{13}\text{C}$) of ostracodes principally responds to two factors: water chemistry and temperature (Chivas *et al.*, 1986). Differences in the physiology of organisms give rise to the so-called vital effects (von Grafenstein *et al.*, 1999). This means that different species inhabiting the same environment have similar responses to environmental factors, but can be offset from one another. Vital effects can explain when an organism appears to be out of equilibrium from the predicted values.

Important to this study is the understanding of the environmental factors that control $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ incorporation in ostracode valves. These are primarily water chemistry and in the case of $\delta^{18}\text{O}$, temperature, rainfall and evaporation (Swart *et al.*, 1996). Strong excursions to more negative values of $\delta^{18}\text{O}$ of *Peratocytheridea setipunctata* that take place prior to 1925 ± 4 correlate to high-rainfall years, and are consistent with relatively fresher conditions or rather constant brackish water conditions in a typical estuary. In contrast, strong positive excursions to heavier $\delta^{18}\text{O}$ values occurred during the mid-1980s. As evaporation proceeds, it preferentially removes ^{16}O and leaves the water behind enriched in ^{18}O ; thus, the $\delta^{18}\text{O}$ value of the water becomes more positive. This may have been the

case for the mid-1980s when heavier oxygen isotopic values were concurrent with a major regional drought in South Florida, as well as with algal blooms and a major die-off of sea grasses (Swart *et al.*, 1999). Evaporation of marine or brackish waters will result in a correlation between salinity and $\delta^{18}\text{O}$, whereas evaporation of freshwater produces no such correlation. Some of the intricacies this difference causes in interpretation of ^{18}O results in the Everglades/Florida Bay system are as follows.

Commonly marine waters have $\delta^{18}\text{O}$ values between 0 and $+1\text{‰}$ SMOW, while freshwater values are more negative. In South Florida, the $\delta^{18}\text{O}$ of rainfall is approximately -3‰ (Swart *et al.*, 1989). During drier years, when precipitation is appreciably lower than the annual mean of 150 cm, the intense evaporation in the Everglades can cause freshwater to have a $\delta^{18}\text{O}$ value as high as $+3\text{‰}$ (in contrast to the marine signal of 0 to $+1\text{‰}$). Reduction in freshwater flow may also allow a greater intrusion of marine water resulting in an increase of isotopic composition as well. However, in this instance the $\delta^{18}\text{O}$ will increase because of the movement of the salt water/freshwater transition inland and not because of the enhanced evaporation. Both cases will result in a negative correlation between salinity and $\delta^{18}\text{O}$. In wet years, the Everglades water is closer in isotopic composition to the original rainfall value ($\sim -3\text{‰}$). Finally, during very wet periods, the freshwater will retain its original negative $\delta^{18}\text{O}$ value and when mixing with marine water it will produce a positive covariance between oxygen and salinity (Nelsen *et al.*, in press).

In coastal waters, the $\delta^{13}\text{C}$ is also highly variable and the dissolved inorganic carbon (DIC) will be highly depleted as a result. The carbon isotopic composition of calcareous organisms can be principally related to the $\delta^{13}\text{C}$ of the DIC pool as well as the physiological state of the organism. Under normal marine conditions, physiological processes are probably most important in controlling interannual variations in the $\delta^{13}\text{C}$ of the calcitic skeleton. In situations such as Oyster Bay, variations in the DIC probably dominate. Variations in the $\delta^{13}\text{C}$ of the DIC are caused by a combination of the oxidation of organic material, which produces water highly depleted in $\delta^{13}\text{C}$, and the introduction of marine waters, which are relatively enriched in $\delta^{13}\text{C}$ (Nelsen *et al.*, in press). During the wet season, Oyster Bay will be inundated by freshwater that will be isotopically depleted in $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$. In contrast, during the dry season, the area will be influenced more by marine water from the Gulf, which will be heavier in $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$. Generally, the ostracode isotopic data from Oyster Bay shows positive correlations between ^{13}C and ^{18}O suggesting a normal interaction between

freshwater and marine waters (Text-fig. 7). Positively correlated $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ deviations suggest an association between terrestrially derived, isotopically light, C and O.

Exceptions to the positive correlation between the $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ in the ostracode data occur in the 1970s, and the 1930s and 1940s. The offset in the 1970s is significant because it occurs immediately prior to a substantial shift towards more positive oxygen and carbon isotopic compositions that are evident in the ostracode isotopic record. At this time, flow in the Shark River Slough and the rainfall record at Homestead and Flamingo are decoupled (Nelsen *et al.*, in press), suggesting a major modification in water flow prior to this time period. The other periods (1930s and 1940s), which exhibit a negative correlation between $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$, are more difficult to understand because of an absence of hydrological data and the lower abundance of ostracodes.

CONCLUSIONS

The following conclusions can be derived from the ostracode fauna and isotopic data. Natural variability in the ostracode communities over time is the result of natural seasonal fluctuations in climate and hydrological conditions. Hurricane events and their effects are the major cause for immediate modifications within ostracode populations. However, these populations are capable of a rapid recovery. Rainfall is the dominant

natural driving force behind long-term variability in microfaunal assemblages.

The Oyster Bay core showed a large decline in ostracode diversity and abundance at about 1980. The timing of this event is best correlated to the onset of the SFWMD "Rainfall Plan" and the modification of the natural flow of freshwater running through Shark River Slough to the drainage basin of Taylor Slough. This cutback in freshwater renovation to Oyster Bay is likely to have induced strong evaporative conditions. In addition, the closing of the Buttonwood canal, also at this time, may have reduced water exchange between Whitewater Bay and Florida Bay, and further stressing Oyster Bay's microfaunal communities.

Strong positive deviations in $\delta^{13}\text{C}$ and $\delta^{18}\text{O}$ for both species, *Peratocytheridea setipunctata* and *Ammonia parkinsoniana* in the mid 1980s were concurrent with a documented major regional drought in South Florida, as well as with algal blooms and a major die-off of sea grasses in Florida Bay (Fourqurean and Robblee, 1999; Robblee *et al.*, 1991).

In general, the isotopic data from Oyster Bay shows positive correlations between ^{13}C and ^{18}O for both *P. setipunctata* and *A. parkinsoniana* suggesting a normal interaction between freshwater and marine waters. An exception that occurred in the 1970s is probably the result of decoupling of rainfall and freshwater flow down Shark River Slough during this time period due to changes in water management.

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CHAPTER 8

DIATOMS AS INDICATORS OF ENVIRONMENTAL CHANGE IN SEDIMENT CORES FROM NORTHEASTERN FLORIDA BAY

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ABSTRACT

Diatom assemblages found in two sediment cores from northeastern Florida Bay indicate fluctuations in both salinity and extent of sub-aquatic vegetation cover during the past 100 years. Diatoms from Russell Bank core 19A indicate that salinity was high prior to the 20th century. Between 1890 and 1920, assemblages dominated by *Mastogloia* species prevail. After 1920, there is a dramatic shift to assemblages dominated by an epipelagic taxon, *Nitzschia granulata*. Around 1950, this taxon declines in abundance and epiphytic species increase. Epiphytic species remain common until about 1972. After 1972, epiphytic diatoms decrease in abundance, and diatoms indicative of higher salinity increase. Similar trends are seen in the Pass Key core 37 (which only spans about 35 years, between 1960–1996). Epiphytic diatoms are common between about 1967 and 1977, and there is an overall trend towards increasing salinity upcore. These findings are in general agreement with other studies of fossil indicators related to salinity and seagrass cover found in Florida Bay sediment cores. These fluctuations may be related to anthropogenic activities, such as the reduction of freshwater flow to Florida Bay from the Everglades as a result of water management practices.

INTRODUCTION

In the past decade, the ecological health of South Florida has been questioned, particularly that of the Everglades and Florida Bay (*e.g.*, Davis and Ogden, 1994; McPherson and Halley, 1996). For instance, recent seagrass die-offs, algal blooms and periods of hypersalinity have generated interest in the extent of anthropogenic impacts on Florida Bay. The advent of ecological studies and monitoring programs in National Parks has allowed managers to move from a belief-based management system to science-based ecosystem management (Davis and Halvorsen, 1996). For example, the Everglades Forever Act was passed in 1994, which mandates that the ecosystem be returned to its “natural state”. One of the pivotal issues that arise from this mandate is how this “natural state” should be defined. Commonly, the goal is to restore the environment to conditions that existed prior to major European anthropogenic disturbance, such as urbanization (*e.g.*, Holling *et al.*, 1994; MacMahon, 1998). In the absence of historical monitoring data that defines the natural variation of the ecosystem, restoration management decisions are exceedingly difficult. Paleoecological applications, which allow for the reconstruction of past environments, provide proxy data to managers interested in restoration (*e.g.*, Brewster-Wingard *et al.*, 1998). Paleoecological techniques have been used successfully to help solve environmental problems such as lake acidification (*e.g.*, Battarbee *et*

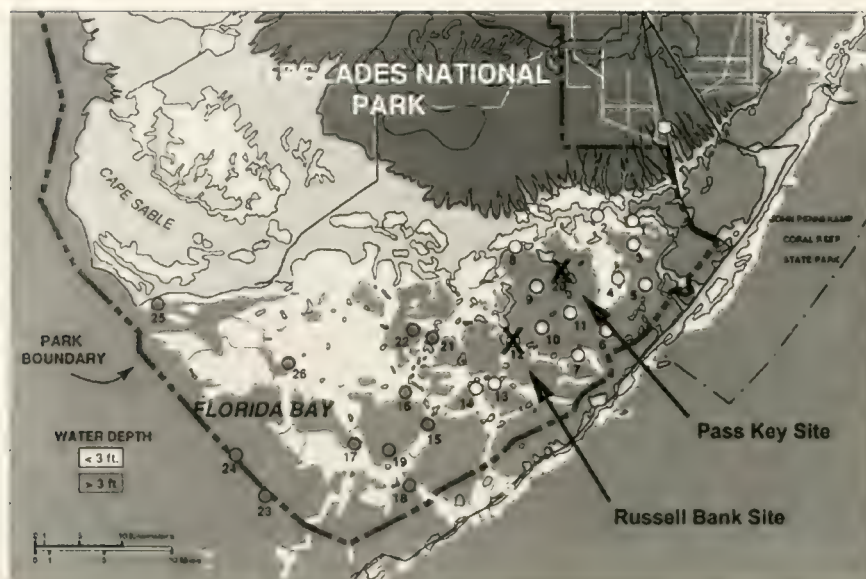
al., 1999) and eutrophication (*e.g.*, Hall and Smol, 1999). More recently, paleoecological techniques have been applied to estuarine systems (*e.g.*, Juggins, 1992; Cooper, 1995a; Brewster-Wingard *et al.*, 1998a; Ishman *et al.*, 1998; Cooper, 1999).

This study deals with the use of diatoms as indicators of environmental change in Florida Bay sediment cores. Diatoms are microscopic algae that commonly occur in aquatic environments. They have a siliceous shell, or frustule, that is generally well preserved in aquatic sedimentary environments. Species designations are based on the morphology of their silica shell, making them particularly attractive as fossil indicators. In addition, species distributions are closely linked to water quality parameters such as pH, salinity, and nutrient availability (*e.g.*, Sweets *et al.*, 1990; Fritz *et al.*, 1991; Dixit *et al.*, 1993; Fritz *et al.*, 1993; Wilson *et al.*, 1994; Cooper *et al.*, 1999).

We present diatom assemblage data from sediment cores from two sites in northeastern Florida Bay. The main objective of the study is to provide a diatom-based reconstruction of environmental conditions in this sub-region of Florida Bay during the last century. We examine past changes in salinity and sub-aquatic vegetation cover.

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Text-figure 1.—A map of Florida Bay with the 26 USGS monitoring sites labeled. The Russell Bank and the Pass Key sites are indicated by the "X."

of the Environment, provided additional support. We thank Laura Pyle for performing the diatom counts for Pass Key core 37. We would also like to thank G. Lynn Brewster-Wingard of the U. S. Geological Survey, Reston, VA, who provided sediment samples for diatom analyses. The Keys Marine Lab, Florida Institute of Oceanography, Long Key, Florida provided field assistance.

METHODS

CORE COLLECTION AND CHRONOLOGY

Sediment cores were collected from two sites: Russell Bank and Pass Key (Text-fig. 1). Russell Bank sediment cores were collected in February 1995 by the U. S. Geological Survey (St. Petersburg, FL) in cooperation with the South Florida Water Management District and the Everglades National Park (Brewster-Wingard *et al.*, 1997). Cores were collected from the south side of Russell Bank (N 25° 03' 50.04", W 80° 37' 29.28") from a seagrass bed, at a water depth of one half meter. Russell Bank core 19A (RB 19A) was taken alongside Russell Bank core 19B (RB 19B), and the two are considered replicate cores. A third core, Russell Bank 19C (RB 19C) was taken 54 m north of cores 19A and 19B. Cores were dated using ^{210}Pb radiometric-dating techniques. At present, only cores RB 19B and RB 19C have been analyzed for ^{210}Pb activity (Brewster-Wingard *et al.*, 1997).

Samples from core RB 19A were used for diatom analyses. Core RB 19A was 140 cm in length and subsamples were taken at 1 cm intervals between 0–

30 cm and at 2 cm intervals between 30–140 cm. Select samples were analyzed for diatoms.

Pass Key core 37 (PK 37) was collected by the U. S. Geological Survey (St. Petersburg, FL) in May 1996. The core was taken at N 25° 08' 52.08" W 80° 34' 28.20". This core was 76 cm in length and was subsampled at 2 cm intervals. Core chronology was established by ^{210}Pb radiometric-dating techniques. Details of the dating methods can be found in Robbins *et al.* (in press).

DIATOM EXTRACTIONS

A modified version of the procedure described by Funkhauser and Evitt (1959) was used to extract diatoms from sediment core samples. Approximately 0.5 mg dry weight sediment was digested for each sample from core RB 19A. For core PK 37, the amount of sediment digested varied between approximately 0.7 and 2.4 mg dry weight per sample. Samples were treated with H_2O_2 , followed by HCl , and finally an HNO_3 and $\text{K}_2\text{Cr}_2\text{O}_7$ digestion. Sand particles were removed by a coarse fractionation procedure.

Measured aliquots of the final diatom slurries were permanently mounted in Naphrax® (Northern Biological Supply, Ipswich, UK) (Refractive Index ≈ 1.7) on microscope slides. Slides were examined with a light microscope at a magnification of 1000X. Light microscope digital images of most diatom taxa were captured via CCD video camera and frame grabber. These images are on file at the Duke University Wetland Center.

DIATOM IDENTIFICATIONS

Taxonomic identifications were aided by a number of resources including Peragallo and Peragallo (1897–1908); Hustedt (1927–1964, 1955); Patrick and Reimer (1966); DeFelice (1976); Stephens and Gibson (1979, 1980a, 1980b); Yohn and Gibson (1982a, 1982b); Foged (1986); Navarro (1982a, 1982b); Krammer and Lange-Bertalot (1986, 1988, 1991a,b); and Cooper (1995b).

However, there are diatom taxa that have yet to be identified to species level. Some of these taxa may not be described in the literature. These taxa were identified to the generic level and given a species letter designation, *e.g.*, sp. A.

For core PK 37, 15 samples were analyzed and between 300–500 diatom valves were enumerated and identified from each sample. For core RB 19A, 31 samples were analyzed and approximately 400 diatom valves were enumerated and identified from each sample.

DATA ANALYSIS

Down-core changes in diatom assemblages were initially analyzed by examining changes in the relative abundance of dominant taxa. Shannon-Wiener diversity, $(-\sum p_i \ln p_i)$, where p_i = the proportion of the total number of valves belonging to the *i*th taxa in the assemblage) was calculated for each sample following Wetzel, 1983. Centric:Pennate (C:P) ratios were calculated for each sample. Centric and pennate are taxonomic terms related to diatom valve (shell) symmetry. In these particular Florida Bay samples, the centric diatoms are primarily planktonic and the pennate diatoms are benthic and epiphytic. The C:P ratio provides a simple index of the relative abundance of planktonic versus benthic and epiphytic diatoms in these samples.

A multivariate ordination technique, detrended correspondence analysis (DCA), was used to analyze the species assemblage data. Detrended correspondence analysis is an indirect ordination analysis that arranges sites along axes based on species composition (ter Braak, 1995). Ordination analyses indicate which sites are similar in species composition. The ordination analyses were based on the percent abundances of the most common diatom taxa in each core. These analyses were done separately for each core. For core PK 37, a total of 43 taxa were included in the analysis. Each of these 43 taxa comprised at least 1% of the total diatom count in at least two samples. Similarly, for core RB 19A, 36 taxa that comprised at least 1% of the diatom assemblage in two or more samples were used. The gradient length for the Pass Key dataset was relatively short (<2.0 standard deviation units). There-

fore, a linear ordination technique, principal components analysis (PCA) was used instead of the unimodal DCA in the final analysis of the Pass Key data (ter Braak, 1995).

A stratigraphically constrained cluster analysis, CONISS (Grimm, 1987), was performed on the same data sets for both cores (PK 37 and RB 19A). This is a program that performs cluster analysis by incremental sums of squares, with the constraint that only adjacent core samples can be merged.

Diatom species distributions are displayed as a ratio to the individual species maximum in the core samples. For example, if the maximum abundance of a given species were 30%, then a particular sample with a percent abundance (for that species) close to 30% would have a ratio close to 1. This form of display allows one to easily examine relative changes in the abundance of the less common species. Some of these less common species are indicative of certain environments, and thus changes in their abundance provide information concerning past environmental conditions.

RESULTS

CORE CHRONOLOGIES

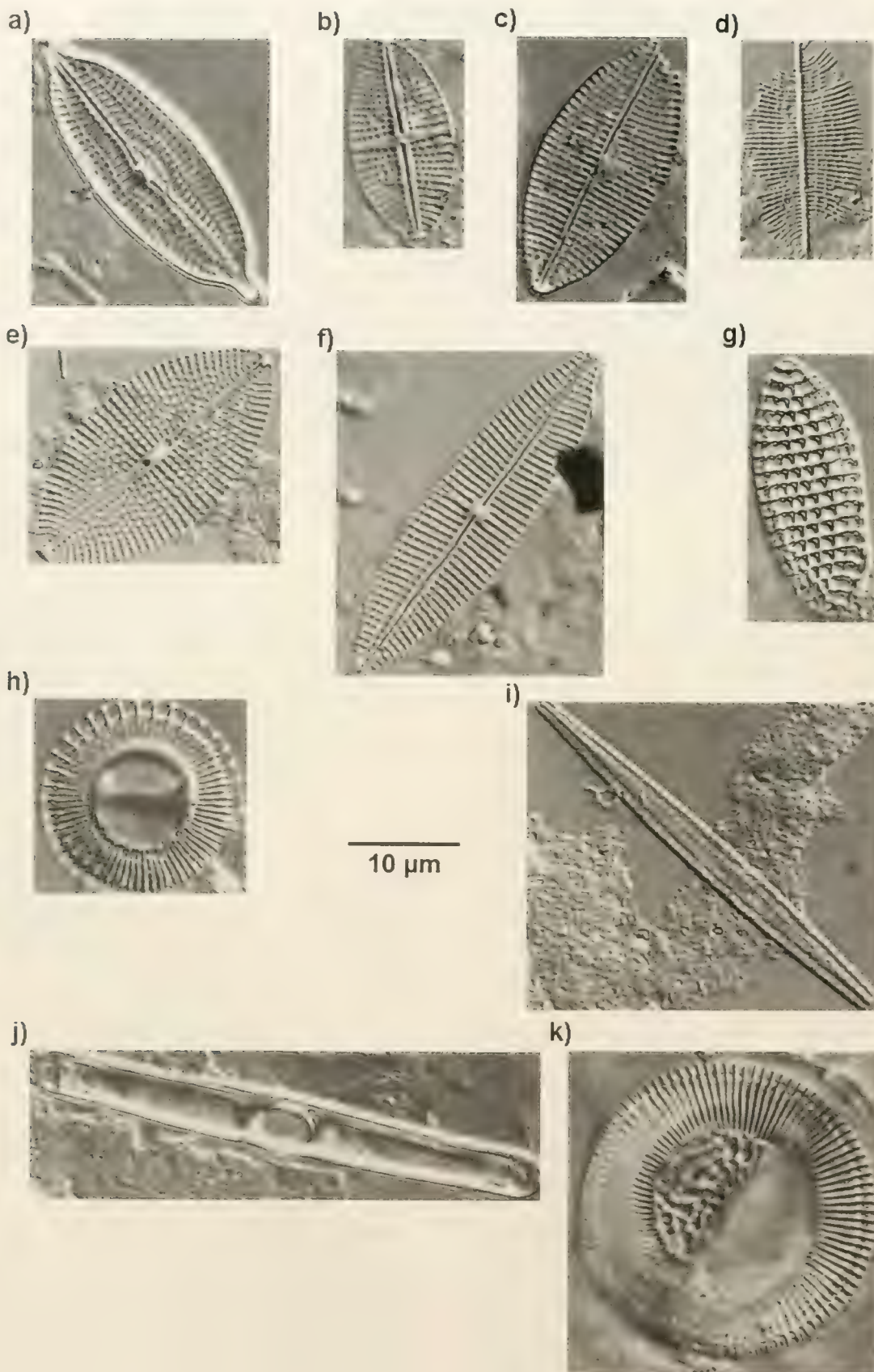
The ^{210}Pb activity curves for cores RB 19A and RB 19C were very similar. Sedimentation rates for these two cores were estimated at $1.22 \text{ cm/yr} \pm 0.05 \text{ cm}$ (Brewster-Wingard *et al.*, 1997). Given this sedimentation rate, core RB 19A is approximately 115 years old, spanning the period from about A.D. 1880 to 1995.

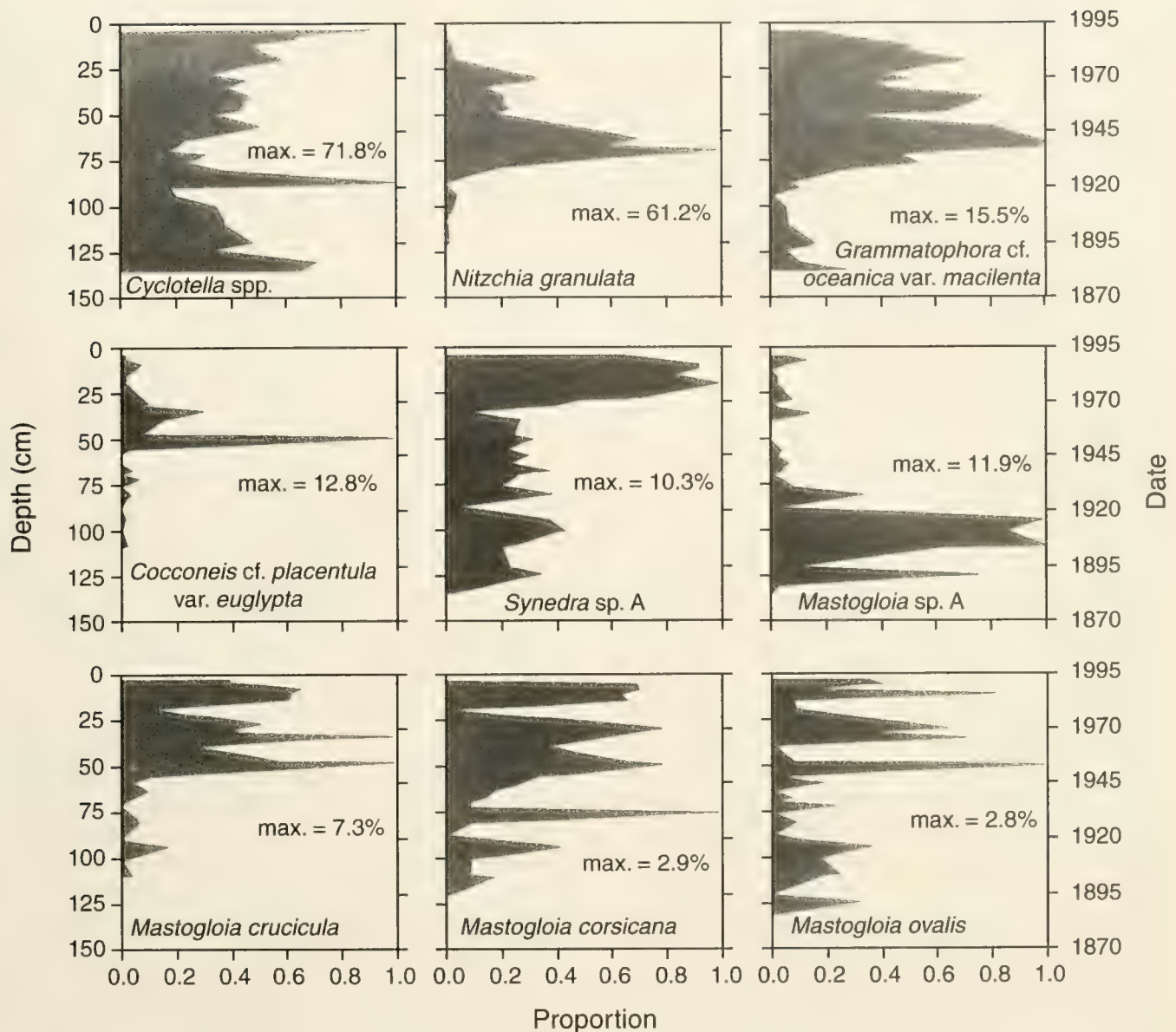
The sedimentation rate for core PK 37 was estimated to be on the order of $2.06 \text{ cm/yr} \pm 0.2$. Evidence from other sources supports this estimation. Aerial photo evidence indicates that the opening south of Pass Key has been filling in since the 1950's (Brewster-Wingard *et al.*, 1998b). In addition, *Casuarina* pollen is present throughout the core indicating relatively recent deposition (less than 100 years) because this species was not introduced to the region until the late 1800's or early 1900's and would therefore not be present at an earlier date. (Brewster-Wingard *et al.*, 1998b).

Russell Bank Core 19A

Diatom Flora

A total of 157 diatom taxa have been identified from core RB 19A. The five most abundant taxa in the core samples examined are *Cyclotella cf. litoralis* Lange and Syversten, *Nitzschia granulata* Grunow, *Cyclotella cf. striata* (Kutz.) Grunow, *Grammatophora cf. oceanica* var. *macilentia* (Wm. Smith) Grunow, and *Synedra* sp. A. Representative images of these taxa are





Text-figure 3.—Relative abundances of select taxa from the Russell Bank core 19A. Relative abundances are standardized to the maximum abundance for each species. Values of 1 indicate a maximum abundance for that species. Samples are plotted by sample depth in centimeters. Dates (based on the average sedimentation rate derived from Pb-210 analyses) are shown on the right.

shown in Text-figure 2. The percent abundance of these species standardized to the maximum abundance of each species are shown in Text-figure 3. The two species of *Cyclotella* are grouped together in the *Cyclotella* graph (Text-fig. 3) because these species were sometimes difficult to distinguish. The maximum

abundance (71.8%) of *Cyclotella* species occurs in the lower part of the core at the 88–90 cm sample interval. A second peak occurs at the top of the core, where the percent abundance reaches 60% of the total diatom count. *Mastogloia* species are most common in the bottom third of the core, comprising an average abun-

Text-figure 2.—Light microscopic photographic images of representative diatoms from Russell Bank core 19A. a) *Mastogloia corsicana* b) *Mastogloia crucicula* c) *Mastogloia* sp. R d) *Cocconeis placentula* var. *euglypta* e) *Mastogloia ovalis* f) *Mastogloia* sp. A g) *Nitzschia granulata* h) *Cyclotella* cf. *striata* i) *Synedra* sp. A j) *Grammatophora* cf. *oceanica* var. *macilenta* k) *Cyclotella* cf. *littoralis*.

dance of 24% between the 124–126 and 90–92 cm samples. The most common *Mastogloia* species in this portion of the core are *Mastogloia* sp. A and *Mastogloia* sp. R. *Mastogloia* species decline in abundance between 80 and 56 cm, with an average abundance of only 6% over this interval (Text-fig. 3). Above the 56–58 cm sample, *Mastogloia* species once again increase with an average abundance of 15%. However, the species differ from those present in the bottom third of the core. In the upper portion of the core, *Mastogloia crucicula* Grunow, *Mastogloia corsicana* Grunow, and *Mastogloia ovalis* A. Schmidt are among the species that increase in abundance (Text-fig. 3).

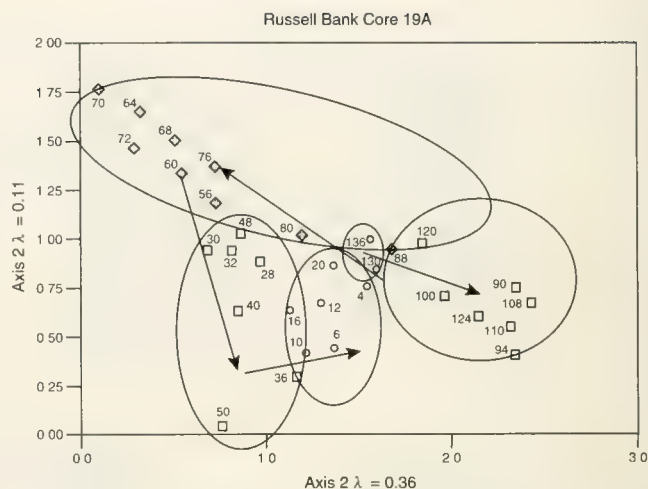
Nitzschia granulata is an important component of the diatom assemblages in the middle of the core between 80 and 28 cm (Text-fig. 3), with an average relative abundance of 26% over this interval, and a maximum abundance of 61% at the 70–72 cm sample. *Nitzschia granulata* declines above 60 cm and decreases to less than 2% of the assemblage in samples above 28 cm. *Grammatophora* cf. *oceanica* var. *macilentia* becomes more common above 80 cm, with an average abundance increasing from 1.5% (below 80 cm) to 9% (above 80 cm), although abundances decline near the top of the core. *Cocconeis placentula* var. *euglypta* (Ehr.) Cleve is most abundant in the 50–52 cm sample, with a maximum abundance of over 12% (Text-fig. 3). The relative abundance of this species is fairly high until about 28 cm. *Synedra* sp. A occurs throughout the core, but percentages of this taxon increase above 30 cm, with a maximum abundance of 10.3% in the 20–21 cm sample (Text-fig. 3).

Detrended Correspondence and Cluster Analyses

In the DCA diagram, samples with similar diatom assemblages have similar axis 1 and 2 scores and are, therefore, closer together on the plot (Text-fig. 4). Arrows drawn between samples (from the bottom to the top of the core) show how the diatom assemblages have changed over the time period represented by the core. Several groups of samples emerge from this analysis. These are the bottom-most group, between 136 and 130 cm, a second group between 130 and 90 cm, a transition group between 90 and 76 cm, a third group between 76 and 56 cm, another transition group between 28 and 56 cm, and the uppermost samples between 28 and 4 cm.

The cluster analysis shows that the greatest change in diatom assemblages occurs between the 80–82 cm and 90–92 cm samples (Text-fig. 5). Other sub-clusters contain samples between 130 and 136 cm, 130 and 90 cm, 90 and 56 cm, 56 and 28 cm, and samples between 28 and 4 cm.

These groupings indicate that the diatom flora can



Text-figure 4.—Detrended correspondence analysis ordination plot based on the diatom assemblages in Russell Bank core 19A. The numbers on the figure indicate sample numbers (the top depth). Circles are drawn around the samples from each zone. Arrows are drawn sequentially from zone I to zone V and indicate how diatom assemblages have changed during the last century. Diatom zones are indicated by the following symbols: Zone I (136–130 cm; 1882–1886 A.D.): filled circles. Zone II (130–90 cm; 1882–1921 A.D.) filled circles. Zone III (90–56 cm; 1921–1949 A.D.) filled diamond. Zone IV (56–28 cm, 1949–1972 A.D.) open squares. Zone V (28–4 cm; 1972–1992 A.D.) stars.

be separated into five time zones represented by depth intervals in the core. The average sedimentation rate of 1.22 cm/yr was used to calculate approximate time intervals: Zone I ca. A.D. 1882–1886 (136–130 cm), zone II ca. A.D. 1886–1921 (130–90 cm), zone III ca. A.D. 1921–1949 (90–56 cm), zone IV ca. A.D. 1949–1972 (56–28 cm), and zone V ca. A.D. 1972–1992 (28–4 cm).

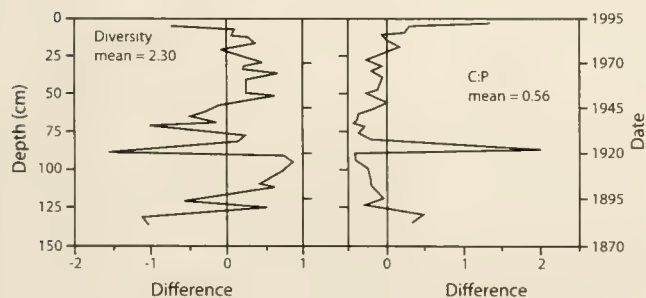
Zone I is characterized by higher percentages of *Cyclotella*, and generally poorer valve preservation than the rest of the core. Zone II is best characterized by high percentages of *Mastogloia* species. Zone III shows a major shift to diatom assemblages dominated by *Nitzschia granulata*. *Grammatophora* cf. *oceanica* var. *macilentia* also increases during this zone. Zone IV has high percentages of *N. granulata*, as well as higher relative abundances of *Mastogloia crucicula*, *M. corsicana*, *M. ovalis*, and *Cocconeis placentula* var. *euglypta*. A decrease in *N. granulata* and increases in *Synedra* sp. A and *Cyclotella* species characterize zone V. According to the DCA, zone V and zone I are similar. This reflects the high abundance of *Cyclotella* in these samples and the low abundance of *N. granulata*. Due to the poorer preservation of valves in zone I, it is not clear if the two zones represent similar diatom communities in other respects.



Text-figure 5.—A stratigraphically constrained cluster analysis of the Russell Bank core 19A diatom assemblages. The Y axis shows sediment depth with the top of the core at the top of the diagram. The second Y axis shows dates based on Pb-210 analyses. The samples counted along with the diatom zones are indicated on the left.

Diatom Species Diversity

The Shannon-Weiner index of species diversity takes into account both the number of species (species richness) in an assemblage and the number of diatom valves represented by each species. For these samples, species richness mirrors the total diversity. For instance, when most of the valves belong to one or a few species, both species diversity and species richness are low. There are several shifts in diatom diversity in core RB 19A (Text-fig. 6). Diversity is low in the bottom-most samples, partly due to a larger number of poorly preserved valves that were difficult to identify, even to the generic level. However, the Pearson correlation coefficient for diversity and the percent

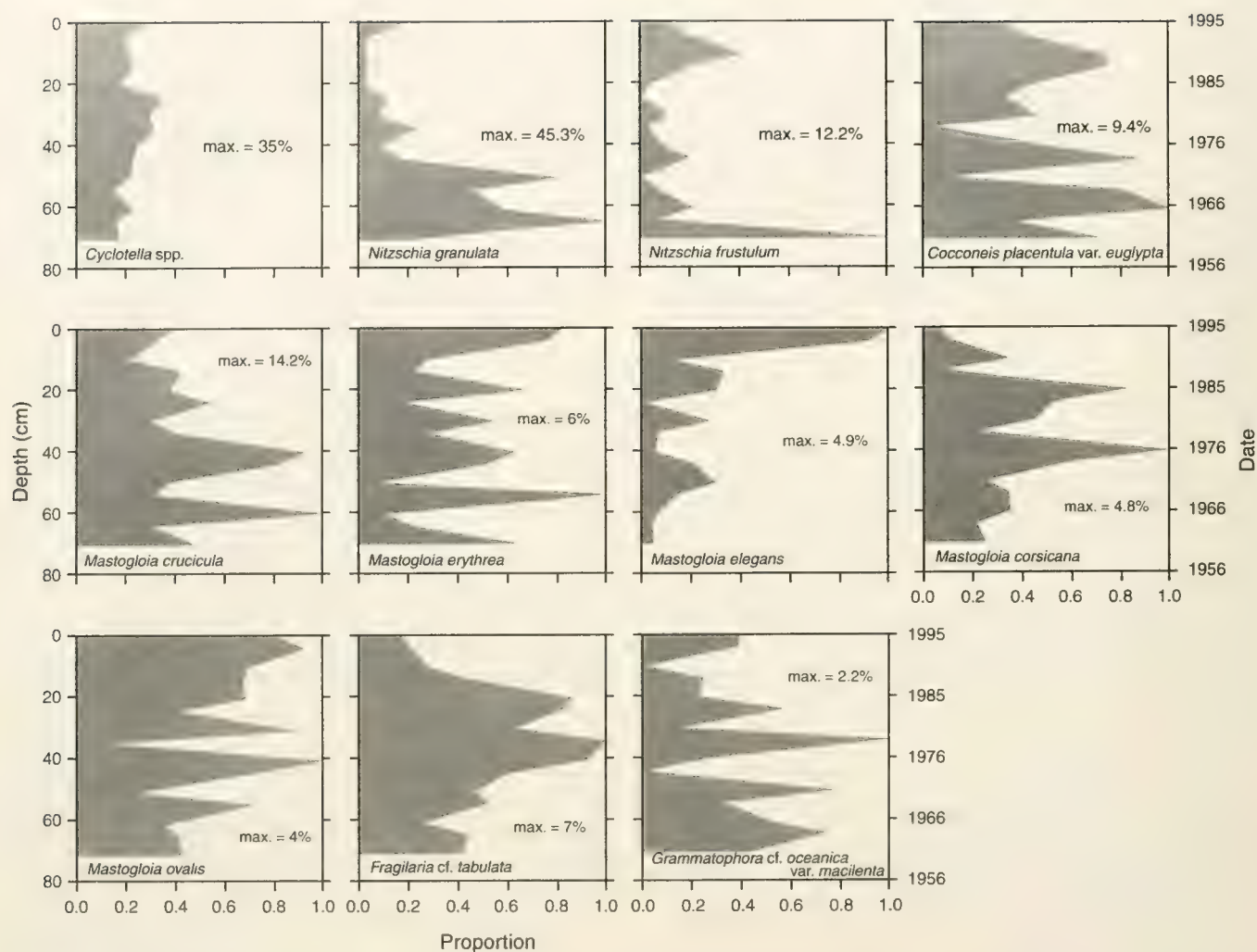


Text-figure 6.—Diversity and C:P profiles for Russell Bank core 19A. Both diversity and the C:P ratio are shown as a difference from the core average. The core mean diversity = 2.30. The core mean C:P = 0.56.

unidentifiable valves (typically broken, poorly preserved valves) is very weak ($r^2 = 0.004$), suggesting that low diversity of samples is not related to poor preservation of diatom valves. Diversity is highest between 90–110 cm, where diatom assemblages are characterized by an increase in *Mastogloia* species, yet preservation quality of the valves is similar to that of the samples in the bottom of the core. There is a very sharp decrease in diversity at 88–90 cm, a sample dominated by *Cyclotella* species. Diversity values recover and then decrease between 56 and 70 cm. This decrease reflects the dominance of *Nitzschia granulata* valves in these samples. Above 50 cm in the core there is an increase in diatom diversity. In general, trends in diversity correspond to the five zones determined by diatom species composition. Diversity values are below average during zone I (A.D. 1882–1886). During zone II (A.D. 1882–1921), values increase and then drop to below average again during zone III (A.D. 1921–1949). Values are above average during zone IV (A.D. 1949–1972) and then decline slightly during zone V (A.D. 1972–1995), but do not fall much below average until ca. A.D. 1995.

Centric : Pennate Ratio

The C:P ratios in Russell Bank core 19A generally reflect the abundance of planktonic *Cyclotella* species. For example, there is a high C:P ratio in the bottom of the core and a high abundance of *Cyclotella* species



Text-figure 7.—Relative abundances of select taxa from the Pass Key core 37. Relative abundances are standardized to the maximum abundance for each species. Values of 1 indicate a maximum abundance for that species. Samples are plotted by sample depth in centimeters. Dates (based on the average sedimentation rate derived from Pb-210 analyses) are shown on the right.

(Text-fig 6). The sharp increase in C:P at the 88–90 cm sample interval also reflects the large amount of *Cyclotella* valves in this sample. Above 88 cm, the ratio declines. There is a general increase in the C:P ratio between 70 and 40 cm. The ratio declines slightly between 40 and 30 cm, and above 30 cm there is a gradual increase.

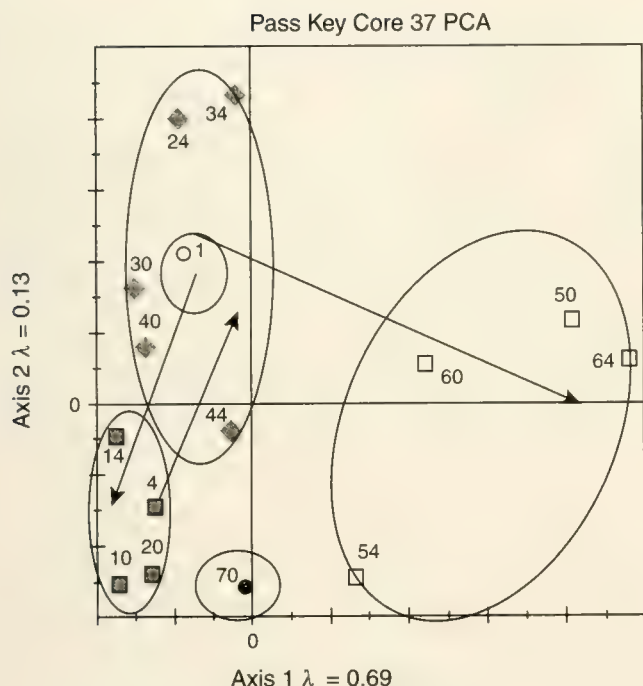
Pass Key Core 37

Diatom Flora

A total of 95 diatom species and varieties were identified from Pass Key core 37. The five species with the highest mean percent abundances are *Cyclotella* cf. *litoralis*, *Nitzschia granulata*, *Mastogloia crucicula*, *Cocconeis placentula* cf. var. *euglypta*, and *Fragilaria* cf. *tabulata* var. *tabulata* (Ag.) Lange-Bertalot. Select

images of diatom taxa from PK 37 can be found in Pyle *et al.* (1998).

The percent abundances of many of the more common species show changes throughout the time period represented by the Pass Key core (Text-fig. 7). *Nitzschia granulata* shows some of the largest changes in abundance (Text-fig. 7). This species is much more common deeper in the core, with percent abundances as high as 45% and 36% in the 64–66 cm and 50–52 cm samples, respectively. Above the 44–46 cm sample, *N. granulata* is much less common, with percent abundances of 10% or less. *Cyclotella* cf. *litoralis* also shows changes in abundance, ranging from 12–18% in the deeper samples, and increasing to over 20% above the 44–46 cm sample (Text-fig. 7). The percent abundance of *C. cf. litoralis* reaches a high of 33% in the



Text-figure 8.—Principal components analysis ordination plot based on the diatom assemblages in Pass Key core 37. The numbers on the figure indicate sample numbers (the top depth). Circles are drawn around the samples from each zone. Arrows are drawn sequentially from zone I to zone V and indicate how diatom assemblages have changed during the last century. Zones are indicated by the following symbols next to the sample number: Zone I (70 cm; 1962 A.D.) filled circle. Zone II (64–50 cm; 1965–1972 A.D.) open square. Zone III (44–24 cm; 1974–1984 A.D.) diamond. Zone IV (20–4 cm; 1987–1995 A.D.) plus sign. Zone V (0 cm; 1996) open circle.

24–26 cm sample, decreases to 17% in the 20–22 cm sample, and resumes an increasing trend towards the surface of the core. *Nitzschia cf. frustulum* (Kutz) Grun. appears to have become less common through time (Text-fig. 7). The percent abundance of *N. cf. frustulum* decreases from a high of 12% in the 70–72 cm sample to <1% in the 64–66 cm sample. Relative abundance of this species remains low until the 10–12 cm sample, where it increases to 5%.

Principal Component and Cluster Analyses

Several groups of samples can be identified from the PCA ordination diagram of the diatom assemblages from core PK 37 (Text-fig. 8). There is a shift in species composition from the bottom-most sample at 70–72 cm to the next sample at 64–66 cm. Samples between 64 and 54 cm group together on the ordination diagram. Between 50 cm and 44 cm there is a transition group. The samples between 40 and 24 cm form a third group. Then there is a shift to a fourth group consisting of the 20–4 cm samples. The top

most sample (0–2 cm) contains an assemblage that is more like the third (40–24 cm) group.

The cluster analysis clearly divides the samples into three main groups: 70–50 cm, 40–24 cm, and 20–0 cm (Text-fig. 9).

Based on the cluster analysis and the PCA, five diatom zones, spanning between 7 and 9 years each, are evident. The average sedimentation rate of 2.06 cm/yr was used to calculate the dates. Zone I ca. A.D. 1962 consists of only the one sample at 70–72 cm. Zone II occurs between ca. A.D. 1965 and 1972 (64–50 cm). The third zone occurs between ca. A.D. 1974 and 1984 (44–24 cm) and zone IV occurs between ca. A.D. 1987 and 1995 (20–4 cm). The last zone V occurs in A.D. 1996 and contains only the uppermost sample at 0–2 cm.

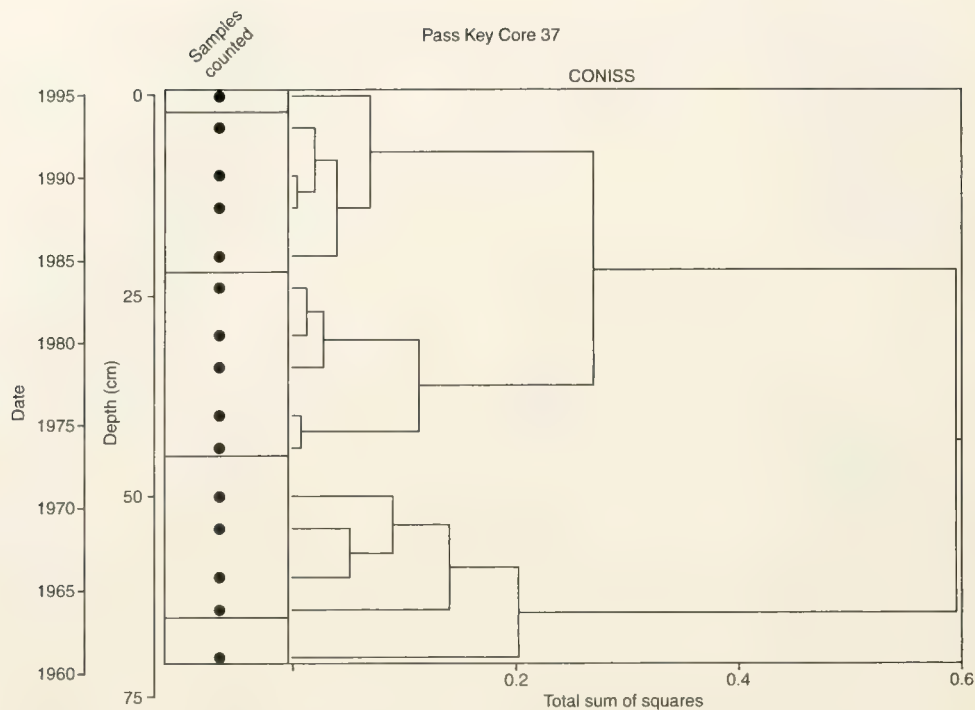
Zone I is characterized by a peak (12%) in the relative abundance of *Nitzschia cf. frustulum* (Text-fig. 7). *Nitzschia granulata* (Text-fig. 7) has an abundance of 9% in zone I, and during zone II, the average abundance increases to 34% with a maximum of 45% and a minimum of 25%. Epiphytic taxa, including *Cocconeis placentula* var. *euglypta*, *Mastogloia crucicula*, and *M. ovalis* increase in abundance between ca. A.D. 1967–1969 (56–60 cm). These taxa show another increase at the lower boundary of zone III, between ca. A.D. 1963 and 1975 (44–40 cm). Zone III is also marked by a sharp decline in *N. granulata* to a zone average of 6%. *Cyclotella cf. litoralis* increases in zone III with a peak relative abundance of 33% (Text-fig. 7). In zone IV, there are increases in *Amphora coffeaeformis* (Ag.) Kutzinger, which has an average of 6.3% during this zone compared to an average of 2% for the previous three zones combined. There is also an increase in *Mastogloia elegans* Lewis to a zone average of 2% (Text-fig. 7). The average abundance of this species in the previous three zones is only 0.6%. Zone V is marked by an increase in *N. granulata* to 7.5%, along with a slight increase in *Cyclotella cf. litoralis*.

Diatom Species Diversity

As in core RB 19A, species diversity in core PK 37 mirrors species richness (Pyle *et al.*, 1998). Species diversity in this core is negatively correlated ($r^2 = 0.75$) with the abundance of *Nitzschia granulata*, the species that dominates the assemblages of zone II. In general, diversity is lowest in zone II and highest in zone IV when there are the lowest percentages of *N. granulata* (Text-fig. 10).

Centric: Pennate Ratio

C:P ratios increase in the Pass Key core from between 0.12 and 0.22 in the deepest samples to over



Text-figure 9.—A stratigraphically constrained cluster analysis of the Pass Key core 37 diatom assemblages. The Y axis shows sediment depth with the top of the core at the top of the diagram. The second Y axis shows dates based on Pb-210 analyses. The samples counted and diatom zones are indicated on the left.

0.35 in the 24–26 cm sample, decreasing to 0.18 in the 20–22 cm sample and then resuming a gradually increasing trend toward the top of the core. The highest ratios occur between 36 and 24 cm (A.D. 1979–1985).

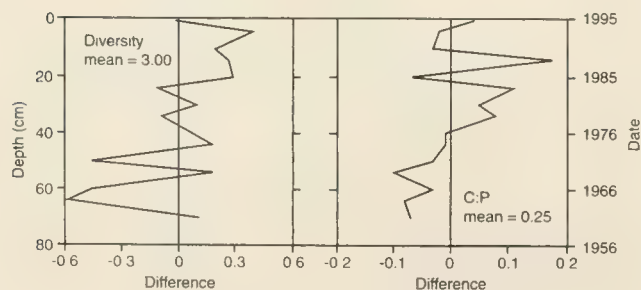
DISCUSSION

RUSSELL BANK 1882–1949

The bottom zone I (A.D. 1882–1888; 130–138 cm) in Russell Bank core 19A is difficult to interpret due to the poor diatom valve preservation. Many of the

broken valve pieces were unidentifiable to species or even genus level. However, it was possible to determine whether the valves were pennate or centric. Thus C:P values are probably not affected by preservation quality. However, the low species diversity may have been affected by preservation quality. Salinity may have been relatively high during this time, as *Cyclotella litoralis* is a marine species (Lange and Syverston, 1989).

The prevalence of two *Mastogloia* species (sp. A and sp. R) in RB 19A zone II (A.D. 1888–1921; 130–90 cm) is also difficult to interpret at the present time. Diversity was generally high during this zone. De-Felice (1976) found that epipelagic (bottom-dwelling) diatom communities were more diverse as compared to epiphytic communities in his study of Florida Bay diatoms. Therefore, these taxa may be part of an epipelagic assemblage. Further study of the literature is necessary in order to determine whether these particular *Mastogloia* taxa have been described, and if any autecology is known. These species were not common in an analysis of diatoms from modern surface sediment samples in Florida Bay (unpublished data). This suggests that there have been significant changes in the diatom assemblages at the Russell Bank site in Florida Bay since around A.D. 1920.



Text-figure 10.—Diversity and C:P profiles for Pass Key core 37. Both diversity and the C:P ratio are shown as a difference from the core average. The core mean diversity = 3.0. The core mean C:P = 0.25.

During zone III (ca. A.D. 1921–1949; 90–56 cm), the salinity around Russell Bank was likely relatively low based on the abundance of *Nitzschia granulata*, a species found in modern assemblages from sites with salinities between 8 and 24 ppt (Huvane, in press). However, the presence of *Grammatophora* cf. *oceanica* var. *macilenta*, a taxon associated with more saline conditions in Florida Bay (Huvane, in press) increases during this period. This conflicting evidence may be explained by salinity fluctuations in the bay. The presence of taxa indicative of less saline conditions may reflect average or minimum salinities during that time period. It is possible that intermittent periods of higher salinity allowed for the increase in the *Grammatophora* species.

RUSSELL BANK AND PASS KEY 1949–1996

The increase in *Cocconeis placentula* var. *euglypta* frustules during zone IV (A.D. 1949–1972; 56–28 cm) suggests that the water was at least periodically brackish at this time. This taxon is characteristic of freshwater (e.g., Patrick and Reimer, 1966), but also occurs in brackish water (e.g., Cooper, 1995b). In a study of Florida Bay surface sediment samples, this taxon was most abundant at the least saline site that had an average salinity of 7.7 ppt (Huvane, in press).

Mastogloia corsicana, a taxon associated with sites in Florida Bay that have salinities between 20 and 33 ppt (Huvane, in press), increases after A.D. 1953 (zones IV and V), although there is also a peak around A.D. 1932 (76–78 cm) during zone III. *Synedra* sp. A, another taxon associated with higher salinity sites in Florida Bay (between 19 and 32 ppt; Huvane, in press) starts to increase at the upper boundary of zone IV. The increase in these taxa along with the decrease in *Cocconeis placentula* var. *euglypta* suggests that salinity was increasing during zone V (A.D. 1972–1992; 28–4 cm).

The diatom assemblages in the Pass Key core 37 suggest that salinity increased during the same general time period, between A.D. 1974 and 1995. This is evidenced by a decrease in *Nitzschia granulata*, and increases in *Mastogloia corsicana*, and *M. elegans* that have been described in the literature as marine (Huvane, in press; Foged, 1984; Yohn and Gibson, 1983b).

Mastogloia corsicana, *M. crucicula*, *M. ovalis* and *Cocconeis placentula* var. *euglypta* were found in seagrass samples collected in February 1999 from Florida Bay (Huvane, unpublished data). These taxa have also been noted elsewhere in the literature as epiphytic (e.g., Patrick and Reimer, 1966; Hustedt, 1927–1964; Navarro, 1982; DeFelice, 1976; Stephens and Gibson, 1979). Higher percentages of these epiphytes in core RB 19A starting around A.D. 1953, indicate that dur-

ing zone IV (A.D. 1949–1972; 56–28 cm,) there was more sub-aquatic vegetation available for colonization by epiphytic diatoms. In the Pass Key core 37, a similar diatom-inferred increase in sub-aquatic vegetation occurs later, between A.D. 1967 and 1977.

In the Russell Bank core 19A, increases in C:P ratios occur between A.D. 1972–1992 (zone V). In the Pass Key core, increases occur between A.D. 1979 and 1984 (zone III). These increases can be interpreted in several ways. The increase in the centric diatom *Cyclotella* cf. *litoralis* could be an indication of increases in salinity as other changes in the stratigraphy of both the Pass Key and the Russell Bank cores suggest. This species has been described as a marine planktonic form (Lange and Syversten, 1989). Another explanation is that there are more planktonic algal blooms, possibly related to increases in nutrients. Such blooms could increase the number of centric planktonic diatoms as well as decrease the number of pennate benthic diatoms by reducing light availability to the bottom. Increased levels of sediment suspension could also serve to inhibit the growth of benthic diatoms. Population declines of seagrass in Florida Bay could also increase this ratio, as many of the pennate diatoms are epiphytic.

COMPARISONS TO OTHER INDICATORS

The diatom inferences concerning salinity and seagrass cover generally coincide with the inferences made from benthic faunal indicators. In the Russell Bank core 19B, benthic foraminifera show significant assemblage changes around 1940, indicating an increase in salinity (Brewster-Wingard *et al.*, 1997). Diatom assemblages also show shifts during this interval, but the salinity inference is ambiguous. Foraminifera assemblages indicative of lower salinities are common between about A.D. 1960–1980 (42–18 cm) (Brewster-Wingard *et al.*, 1997). The increase in the diatom *Cocconeis placentula* var. *euglypta* between A.D. 1953 and 1972 (28–50 cm) also suggests lower salinities. Foraminifera assemblages indicate a shift to higher salinities between A.D. 1975 and 1980 (24–18 cm) (Brewster-Wingard *et al.*, 1997). This up-core increase in salinity is also indicated by changes in diatom assemblages starting around A.D. 1972.

In the Pass Key core 37, foraminifera remains indicate increases in salinity between A.D. 1965 and 1978 (64 and 38 cm), and after about A.D. 1989 (14 cm) (Brewster-Wingard *et al.*, 1998a). Diatom indicators suggest an increase in salinity starting around A.D. 1975 (44 cm). However, one of the salinity indicators, *Mastogloia elegans*, does not increase until after A.D. 1986 (20 cm), suggesting that there may

have been shifts in salinity between A.D. 1975 and 1986.

Mollusc data suggests that seagrass is the dominant substrate in the time period between A.D. 1921–1976 (88–22 cm) in core RB 19B (Brewster-Wingard *et al.*, 1998b). However, the highest percentages of mollusc species indicative of seagrass occur after A.D. 1948. The relative abundances of epiphytic diatoms in core RB 19A indicate that seagrass is dominant between ca. A.D. 1953 and 1972 (50–28 cm). Between about A.D. 1921–1948 (88–56 cm), *Nitzschia granulata* abundances increase, and this species has not been noted in grass samples from Russell Bank, but it has been noted in surface sediments from both Russell Bank and Pass Key (unpublished data). Thus, the diatom data suggest that there was some bare sediment available for the colonization of this diatom species during this interval.

In the Pass Key core, mollusc data suggest that seagrass cover increases between A.D. 1965 and 1978. This agrees with the diatom assemblage data, which shows high abundances of epiphytic diatoms during this period.

Minor discrepancies between diatom indicators and faunal indicators (foraminifera and molluscs) may be explained by a variety of factors. For example, the spatial scale that is reflected by each group may differ. Microscopic diatoms may be deposited in sediments further away from their original habitat than the larger mollusc shells.

Other factors to consider are the relative sensitivity of the indicators to environmental change and the reproductive rates of the organisms. Diatoms are known to respond fairly quickly to changes in water quality (Dixit *et al.*, 1992) and therefore may show an earlier response to changes in salinity. This appears to occur at the Russell Bank site where diatom indicators of increasing salinity appear around A.D. 1972, while faunal indicators do not appear until A.D. 1975. However, this pattern was not recognized in the Pass Key core, and may only reflect variations in the sedimentation rates between cores RB 19A and RB 19B.

IMPACTS ON DECISION MAKING

These data have several implications for management decisions and research goals. Fluctuations in both

seagrass cover and salinity suggest that management plans should be designed to incorporate some degree of natural variability. Future research should address questions concerning specific limits of natural variability such as the natural extremes of salinity and the periodicity of such extremes. It would also be useful to know the extent of seagrass cover prior to the major anthropogenic disturbances in South Florida. The fossil data suggest that seagrass cover has fluctuated in the past, and these fluctuations are important in our understanding of seagrass population dynamics. In addition, the mechanisms that initiate both natural and anthropogenic-induced variability need further exploration in order to implement remediation.

SUMMARY

The data from Russell Bank core 19A suggest that there have been fluctuations in salinity and seagrass cover during the last hundred years. This is consistent with what has been found in other studies of sediment cores from Florida Bay. Diatom indicators of salinity and seagrass coverage show the same general patterns as other fossil indicators from these cores. In the Russell Bank core 19A, the earliest diatom assemblages indicate a period of higher salinity. Between A.D. 1890 and 1920, epiphytic diatoms were not common, supporting mollusc data that indicates bare sediment as the dominant substrate during this period. Epiphytic diatoms increase in abundance after about A.D. 1950 and remain common until about A.D. 1972, which is consistent with the mollusc data that indicates a decline in epiphytes around A.D. 1970. In the Pass Key core 37, diatom epiphytes increase at the same time as mollusc epiphytes (between A.D. 1967–1977).

There are indications of salinity fluctuations after ca. A.D. 1950 in both cores. The presence of *Cocconeis placentula* var. *euglypta* between ca. A.D. 1953 and 1970 in core RB 19A suggests that salinities were lower during this time. Diatom indicators suggest increases in salinity in both cores after ca. A.D. 1970. This is also consistent with faunal indicators of salinity.

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CHAPTER 9

HISTORICAL TRENDS IN EPIPHYTAL OSTRACODES FROM FLORIDA BAY: IMPLICATIONS FOR SEAGRASS AND MACRO-BENTHIC ALGAL VARIABILITY

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ABSTRACT

Living and fossil epiphytal ostracodes from central and eastern Florida Bay were investigated to determine historical trends in seagrass and macro-benthic algal habitats during the past century. Living assemblages collected in February and July, 1998 from 15 sites throughout Florida Bay revealed that *Loxoconcha matagordensis* and *Malzella floridana* are the dominant species living on *Thalassia* and that *Xestoleberis* spp. is the most abundant ostracode group living on *Syringodium* and marine algae such as *Chondria*. *Peratocytheridea setipunctata* is a species that is common on muddy substrates and on *Halodule*.

Temporal trends in epiphytal ostracode abundance were reconstructed from isotopically-dated sediment cores from Whipray mudbank, Russell Bank, Bob Allen mudbank, Pass and Park Keys, Taylor Creek (near Little Madeira Bay) and Manatee Bay. The results show that there have been frequent changes in the relative frequencies of *L. matagordensis*, *M. floridana*, and *Xestoleberis* over the past century. Prior to the mid-20th century, seagrass- and algal-dwelling ostracode species were relatively rare at our sites in central and eastern Florida Bay. Ostracode assemblages living between about 1900 and 1940 were characterized by moderate to large proportions (10–>60%) of *Peratocytheridea setipunctata* when *Thalassia*- and macro-benthic algal-dwelling species were less common than during the later half of the 20th century. Beginning about 1930, and continuing until 1950, *P. setipunctata* populations experienced significant declines while *L. matagordensis* and *Xestoleberis* increased progressively from 0–10% to >25–40%, depending on the site. This faunal shift suggests that there has been a greater abundance and/or density of subaquatic vegetation in central Florida Bay over the past 50 years than in the prior half century. Since 1950, several sites in central and eastern Florida Bay have experienced large swings in the proportion of seagrass and macro-benthic algal-dwelling species suggesting subaquatic vegetation has been extremely dynamic spatially and temporally over decadal timescales. Some of these oscillations, such as the decline in *L. matagordensis*, *Xestoleberis*, and *M. floridana* during the 1970s and early 80s may represent large-scale dieoffs. The possible influence of climatological factors on salinity and epiphytal ostracodes is also discussed.

INTRODUCTION

Growing efforts to restore polluted and disturbed coastal and estuarine ecosystems to a more natural state rely increasingly on retrospective paleoecological analyses using isotopically-dated sediment cores to establish ecosystem trends and to better understand ecosystem functioning (e.g., Brush 1986; Vallette-Silver 1993). Paleoecological studies are especially important because few monitoring programs have been in place for a long enough period to sufficiently establish the natural range of habitat variability both prior to, and subsequent to human influence. Moreover, in addition to anthropogenic disturbance of ecosystems, extrinsic factors such as climatic variability are also critical aspects to estuarine functioning (Peterson *et al.*, 1995; Cronin *et al.*, 2000).

Florida Bay, a large (2,200 km²), shallow (<3 m), tropical to subtropical lagoon is one such ecosystem believed to have been affected by human activities over

the past century. For example, Smith *et al.* (1989) suggested that canal construction from 1912 to 1931 decreased freshwater flow into Florida Bay, especially through Shark River Slough, and led to hypersalinity. Declines in seagrass populations in parts of Florida Bay since 1987 have been attributed to chronic hypoxia resulting from human alteration of freshwater inflow from the Everglades, and to pathogenic slime molds (Zieman *et al.*, 1989; Robblee *et al.*, 1991). McIvor *et al.* (1994) pointed out that, in addition to its impact on seagrasses, hypersalinity of Florida Bay also may have contributed to recent increases in mangrove mortality. They compiled measurements of salinity obtained over the past 40 years showing that, since at least the late 1950's, seasonal hypersalinity has characterized some regions. Salinity values reached as high as 50 to 70 parts per thousand (ppt) in eastern and central parts of the bay. Light and Dineen (1994, p. 48) expressed the widely held view that human alteration of Everglades hydrology is unprecedented for the late Holocene as follows:

"The first reclamation efforts in the Everglades began in 1881. Just over 100 years later, Governor Graham formally embraced a system-wide restoration initiative entitled 'Save Our Everglades.' More has happened to the Everglades between these two benchmarks than in the preceding 50 centuries."

Given the temporally and spatially incomplete historical monitoring record of Florida Bay, several paleoecological studies have been conducted to reconstruct various ecosystem parameters. Smith *et al.* (1989) concluded, on the basis of analyses of autofluorescence of a *Solenastrea* coral skeleton from Peterson Key in the Atlantic transition zone of Florida Bay that canal construction severely diminished fresh water inflow into Florida Bay, especially through Shark River Slough, reaching minimal flow around 1931. They argued that the hydrological impact of canal construction was severe enough to disrupt the natural 4- to 6-year periodicity of freshwater inflow resulting in unprecedented episodes of hypersalinity. Swart *et al.* (1996a) attributed carbon and oxygen isotopic variability in a *Solenastrea* colony from the Lignumvitae Basin, also in the Atlantic transition zone of Florida Bay, to construction of the Florida East Coast Railway between 1905 and 1912. They also suggested that frequent hurricanes between 1912 and 1948 caused greater exchange of water between the bay and reef areas, but that after 1948, decreased hurricane activity led to the retention of organic material in the bay and the initial stages of eutrophication. Brewster-Wingard *et al.* (1998) analyzed mollusks and foraminifers from four of the sediment cores examined in this study (Bob Allen, Russell, Taylor, and Pass) to determine the long-term trends in salinity and benthic habitats. Their study shows that subtle shifts in the faunal distributions occur around 1910, but after 1940, the pattern departs substantially from the pre-1900 pattern. The amplitude of shifts in salinity indicators increased from 15%–20% about the pre-1900 mean to 40%–60% about the post-1940 mean. In general, there was an increase in epiphytal molluscan species throughout this century; which Brewster-Wingard *et al.* suggested might be due to changes in water-management practices. Ishman *et al.* (1998) found on the basis of paleoecological data that environments of Manatee Bay had changed significantly over the past century.

Despite the growing amount of paleoecological data, there is still a large degree of uncertainty about the ecosystem history of Florida Bay and the factors that cause interannual and interdecadal variability in Florida Bay environments. The present study is designed to address the scale, timing and possible causes of subaquatic vegetation (seagrasses and macro-ben-

thic algae) variability in Florida Bay using quantitative analyses of ostracodes from sediment cores from central and eastern Florida Bay, and from Manatee Bay just outside the northeast margin of Florida Bay (Text-fig. 1). This study has two parts. First, we conducted a study of the dominant ostracode taxa living on modern seagrass (especially *Thalassia*) and marine algae in Florida Bay. Second, we examined trends in seagrass and algal-dwelling species preserved in sediment cores.

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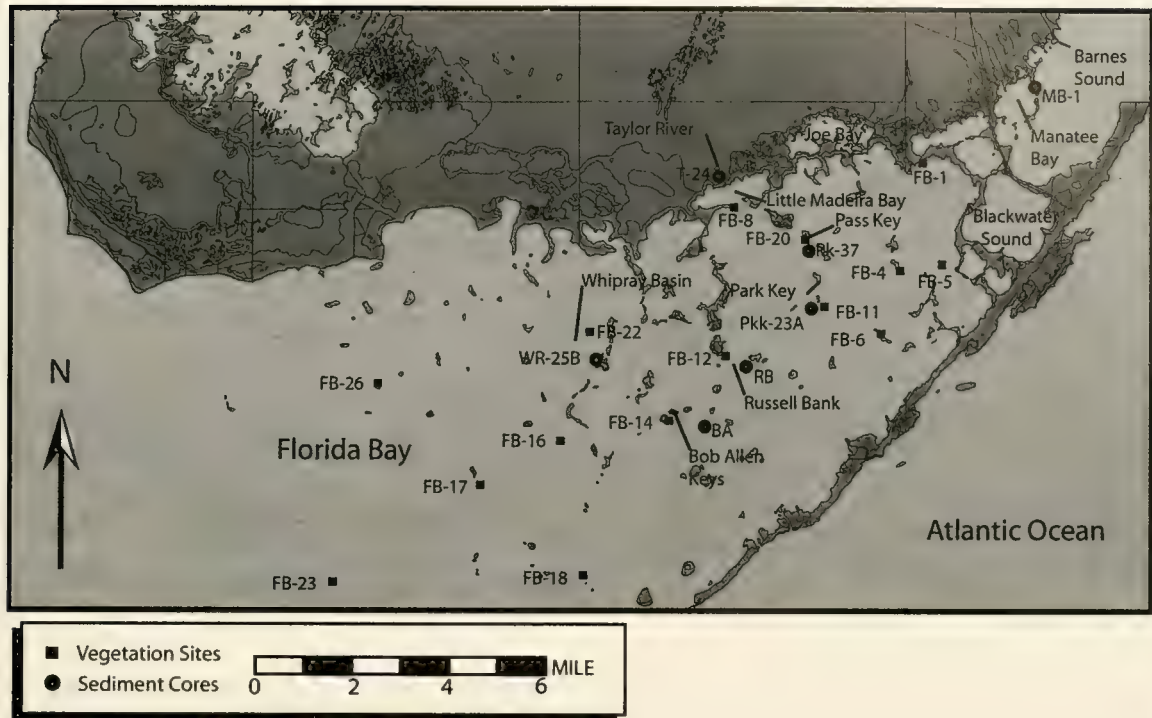
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MATERIAL AND METHODS

MODERN ECOLOGICAL SAMPLES

Epiphytal ostracodes were studied from samples of living seagrasses and macro-benthic algae collected from 15 stations in February and July 1998 in order to obtain quantitative data on species that live on subaquatic vegetation during winter and summer months (Text-fig. 1). These samples were divided into three substrate groupings, those with mainly *Thalassia*, those with mainly macro-benthic algae, and those with primarily *Halodule* grasses. The macro-benthic algae included mostly *Laurencia*, *Chondria*, and *Polysiphonia*; the seagrasses were *Thalassia*, *Halodule* and *Syringodium*. Two sites with coarse shelly substrate were also examined.

After washing vegetation in a 63 μm sieve with tap water, the first 100 individual ostracode specimens were picked with fine brush under a binocular microscope from the size fraction >150 to 850 μm . This size fraction contains the adults and several juvenile instars of all common podocopid ostracodes living in Florida Bay.



Text-figure 1.—Map showing location of modern ostracode samples (squares labeled FB-) and sediment cores at Whipray, Russell, Bob Allen, Park, Pass, Manatee Bay (MB-1), and Taylor Slough.

SEDIMENT CORE SITES

Seven sediment cores were collected along a southwest/northeast transect running from Whipray Key in central Florida Bay to Manatee Bay on the margin of Barnes Sound (Text-fig. 1, Table 1). Cores were taken by hand using a large-diameter hand-driven piston corer ranging in length from 74 cm (Pass Key) to 156 cm (Bob Allen Key). Five cores came from mudbanks in <1 m of water from the central part of Florida Bay (Text-fig. 1): one each from Whipray mudbank (WR-25B), Bob Allen mudbank (BA-6-A), Russell Bank (RB-19-B), Pass Key (PA-37) and Park Key (PK 23-A). One core came from the transition zone in Little Madeira Bay near the mouth of Taylor Creek (T-24)

and another core was taken from Manatee Bay (MB-1) located on the western edge of Barnes Sound, near the northeast part of Florida Bay. Information on each core site is given in Table 1, in preliminary reports (Wingard *et al.*, 1995; Brewster-Wingard *et al.*, 1997; Ishman, 1997), and at the website <http://geology.er.usgs/gmapeast/fla/home.html>.

Whipray Keys are located in central Florida Bay; the core was taken on a mudflat on the eastern side of Whipray basin. The core has a top mixed layer to 12 cm representing the past ~15–20 years; below this, the ^{210}Pb -determined sediment accumulation rate is 0.43 cm/year until reaching equilibrium at 40 cm. Below this level, the material is too old for ^{210}Pb dating. The

Table 1.—Core site information for South Florida paleoecology of ostracodes.*

Site	Latitude	Longitude	Core length	Water depth	Sediment accumulation rate #	Sampling interval
Russell Key (19-B)	25°03.83'N	80°37.49'W	140 cm	0.51 m	1.22	2 cm
Bob Allen Key (6-A)	25°01.39'N	80°39.41'W	156 cm	0.6 m	0.75–1.04**	2 cm
Manatee Bay (MB-1)	25°15.69'N	80°24.06'W	120 cm	~1.0 m	~1.0	2 cm
Taylor Creek (T-24)	25°11.4'N	80°38.4'W	86 cm	~0.5 m	NA	2 cm
Park Key (PKK-23A)	25°10.45'N	80°57.46'W	86 cm	~1 m	0.78	2 cm
Pass Key (PK-37)	25°14.78'N	80°40.82'W	74 cm	~1 m	2.06	~3 cm
Whipray (WR-25B)	25°07.12'N	80°73.85'W	80 cm	~1.25 m	0.43	5 cm

* Sources: Bob Allen and Russell cores: Wingard *et al.* (1995), Brewster-Wingard *et al.* (1997); Manatee Bay cores: Ishman *et al.* (1996, in press), respectively. # centimeters per year. ** Higher rate was used in Figures 8–11.

Table 2.—Florida Bay vegetation Ostracode abundances.

Month	Sample ID	ID number	Salin	Temp	Sub- strate*	<i>L. mata- gordensis</i>	<i>Mal- zella flori- dana</i>	<i>P. seti- punc- tata</i>	<i>Xesto- leberis</i>	Total	Vegetation
Jul-98	FB1A	3	26.9	31.3	G	13	52	1	5	84	<i>Thalassia</i> , <i>Laurencia</i> , <i>Polysiphonia</i> ?, <i>Halodule</i>
Jul-98	FB4A	1	32.2	32.9	G	17	35	4	16	108	<i>Thalassia</i> , <i>Halodule</i> , <i>Laurencia</i>
Jul-98	FB5A	2	31.9	33.4	A	22	12	33	14	97	<i>Chondria</i> ?, <i>Laurencia</i> ?, <i>Polysiphonia</i> ?, <i>Batophora</i>
Jul-98	FB6A	1	35.9	33.3	G	14	6	5	41	88	<i>Thalassia</i>
Jul-98	FB8A	2	23.9	30.9	A	12	26	1	59	100	<i>Chondria</i> / <i>Laurencia</i> ?, <i>Polysiphonia</i> ?, <i>Chondria</i> ?, <i>Acetabularia</i> , <i>Thalassia</i> , <i>Batophora</i> , <i>Sargassum</i> <i>Thalassia</i> , <i>Polysiphonia</i> ?(<i>Chondria</i> ?)
Jul-98	FB11A	2	33.1	33	G	11	49	5	24	106	<i>Halodule</i> , <i>Thalassia</i>
Jul-98	FB12A	2	37	34.6	G	5	30	24	4	98	<i>Halodule</i>
Jul-98	FB14	1	41	33	G	0	4	67	1	89	<i>Halodule</i>
Jul-98	FB16	2	38.7	29.4	G	5	9	2	84	103	<i>Thalassia</i> , <i>Laurencia</i> , <i>Batophora</i>
Jul-98	FB17	1	36.3	28.4	G	38	3	0	30	79	<i>Thalassia</i> , <i>Polysiphonia</i> , <i>Penicillus</i> , <i>Halodule</i>
Jul-98	FB18	2	37.2	29.3	A	28	2	2	41	99	<i>Syringodium</i> , <i>Halimeda incrassata</i>
Jul-98	FB20A	3	28.2	32	G	21	21	1	27	106	<i>Thalassia</i> , <i>Polysiphonia</i>
Jul-98	FB22	1	39.9	30.4	G	11	22	1	58	97	<i>Thalassia</i> , <i>Laurencia</i> , <i>Chondria</i> / <i>Laurencia</i> , <i>Halodule</i> <i>Polysiphonia</i> ?(<i>Chondria</i> ?)
Jul-98	FB23	4	36.8	31.9	A	0	0	1	26	28	<i>Chondria</i> / <i>Laurencia</i> ?, <i>Thalassia</i> , <i>Hal- odule</i> , <i>Syringodium</i> , <i>Laurencia</i>
Jul-98	FB26	2	35.4	33.3	G	51	3	26	12	97	<i>Halodule</i>
Feb-98	FB1	1	15.8	21	A	52	23	0	19	118	<i>Laurencia</i> , <i>Thalassia</i>
Feb-98	FB1	4	15.8	21	G	21	92	4	11	151	<i>Thalassia</i> , <i>Halodule</i> , <i>Laurencia</i>
Feb-98	FB1	5	15.8	21	G	29	33	0	13	92	<i>Thalassia</i> , <i>Polysiphonia</i> , <i>Laurencia</i>
Feb-98	FB11	1	19.3	19.4	G	17	51	15	11	112	<i>Thalassia</i> , <i>Polysiphonia</i>
Feb-98	FB11	2	19.3	19.4	A	18	7	0	32	65	<i>Chondria</i> , <i>Thalassia</i>
Feb-98	FB11	3	19.3	19.4	G	1	24	0	0	31	<i>Halodule</i> , <i>Thalassia</i>
Feb-98	FB11	5	19.3	19.4	G	21	38	12	0	98	<i>Thalassia</i> , <i>Chondria</i> , <i>Polysiphonia</i>
Feb-98	FB12	1	20.7	21.6	A	1	0	0	1	2	<i>Sargassum</i>
Feb-98	FB12	2	20.7	21.6	A	28	13	0	34	82	<i>Chondria</i> , <i>Polysiphonia</i> , <i>Laurencia</i> , <i>Thalassia</i>
Feb-98	FB12	3	20.7	21.6	G	8	43	9	13	97	<i>Thalassia</i>
Feb-98	FB12	4	20.7	21.6	G	2	1	0	0	5	<i>Halodule</i>
Feb-98	FB12	5	20.7	21.6	G	11	37	25	1	113	<i>Thalassia</i> , variable
Feb-98	FB14	1	26.9	23.8	G	35	19	10	62	140	<i>Ruppia</i> , <i>Halodule</i> , <i>Thalassia</i> , <i>Laurencia</i>
Feb-98	FB16	1	30.1	26.3	G	100	1	0	9	115	<i>Thalassia</i> , <i>Laurencia</i> , <i>Batophora</i>
Feb-98	FB16	2	30.1	26.3	A	57	2	0	58	118	<i>Laurencia</i> , <i>Batophora</i> , <i>Thalassia</i>
Feb-98	FB16	3	30.1	26.3	A	70	18	1	35	128	<i>Polysiphonia</i> , <i>Batophora</i> , <i>Thalassia</i> , <i>Halodule</i>
Feb-98	FB17	1	31.7	25.9	G	7	1	2	7	22	<i>Thalassia</i> , <i>Chondria</i>
Feb-98	FB17	2	31.7	25.9	A	18	2	0	28	117	<i>Chondria</i> , <i>Thalassia</i>
Feb-98	FB17	3	31.7	25.9	A	40	9	2	40	115	<i>Chondria</i> , <i>Polysiphonia</i> , <i>Thalassia</i> , <i>Halodule</i> , <i>Laurencia</i>
Feb-98	FB18	2	29.7	24.9	A	20	0	1	16	57	<i>Syringodium</i>
Feb-98	FB20	1	17.1	19.9	G	15	7	0	3	33	<i>Thalassia</i> , <i>Polysiphonia</i>
Feb-98	FB20	2	17.1	19.9	G	0	16	0	2	28	<i>Halodule</i>
Feb-98	FB20	3	17.1	19.9	A	2	1	0	0	3	<i>Chondria</i> , <i>Polysiphonia</i> , <i>Thalassia</i>
Feb-98	FB20	4	17.1	19.9	A	0	1	0	2	6	<i>Chondria</i> , <i>Batophora</i> , <i>Thalassia</i>
Feb-98	FB20	5	17.1	19.9	A	5	2	0	0	7	<i>Polysiphonia</i>
Feb-98	FB21	1	28.9	24	G	42	7	0	15	74	<i>Thalassia</i> , <i>Halodule</i> , <i>Laurencia</i>
Feb-98	FB21	shell	28.9	24	S	22	8	47	2	111	shell in soft mud

Table 2.—Continued.

Month	Sample ID	ID number	Salin	Temp	Substrate*	<i>L. mata-gordensis</i>	<i>Mal-zella flori-dana</i>	<i>P. pun-cata</i>	<i>Xesto-leberis</i>	Total	Vegetation
Feb-98	FB22	1	30.2	24.9	G	26	18	1	25	80	<i>Thalassia, Laurencia</i>
Feb-98	FB23	1	30.2	24.9	G	1	0	0	1	5	<i>Syringodium, Thalassia, Chondria, feathery algae</i>
Feb-98	FB26	1	31.6	27.6	G	52	2	1	22	94	<i>Halodule, tulip-like algae, Thalassia, Laurencia, Chondria</i>
Feb-98	FB26	2	31.6	27.6	G	9	0	1	5	15	<i>Halodule, Thalassia</i>
Feb-98	FB4	4	16.7	21.6	G	16	9	2	10	48	<i>Thalassia, Sargassum, Polysiphonia</i>
Feb-98	FB5	1	17.6	21.9	A	9	8	2	78	104	<i>Polysiphonia, Batophora, Chondria (2 species), Thalassia, Laurencia, Halodule</i>
Feb-98	FB5	2	17.6	21.9	A	24	42	3	34	128	<i>Laurencia, Acetabularia, Enteromorpha, Halodule, Batophora</i>
Feb-98	FB5	3	17.6	21.9	A	4	0	0	4	8	<i>Laurencia, Chondria, filamentous green algae</i>
Feb-98	FB5	5	17.6	21.9	A	29	19	0	60	126	<i>Laurencia, green mossy filamentous algae, Batophora, Chondria, Halodule, Thalassia</i>
Feb-98	FB6	shell	20	21	S	4	10	69	4	128	shell lag
Feb-98	FB8	1	15.2	20	G	18	68	0	17	121	<i>Polysiphonia, Chondria, Thalassia</i>

* Substrate abbreviations: A = algal, G = seagrass, S = sand/shell.

slower sediment accumulation rate at Whipray Keys means that a 2-cm sample represents on average about four years of sediment.

Russell Bank is a few hundred meters across and about 1 km long. Wanless and Tagett (1989) studied the stratigraphy of Russell Bank and concluded that during its construction, it had accreted in a southward direction. The Russell Bank core (RB-19-B) was taken from the top of Russell Key mudbank. The Bob Allen core (BA-6-A) was obtained from the flank of another accretional mudbank located about 4 km to the southwest of Russell Key. Both the Russell and Bob Allen cores have been the subject of intensive isotopic dating, and the age model based on ^{210}Pb and ^{137}Cs of Robbins *et al.* (2000) is used here.

Park Key core was taken on the western side of the bank, which, based on aerial photographs, is the accreting side of the bank. The core was taken in 10 cm of water on top of the bank.

The Whipray, Russell, Bob Allen, Park and Pass Keys sites are strategically situated in the central and eastern parts of Florida Bay where periods of summertime hypersalinity have occurred, especially during years with low freshwater discharge (Robblee *et al.*, 1991; Fourqurean *et al.*, 1993).

The Manatee Bay core (MB-1) site is located to the northeast of Florida Bay (the "inner zone" of Wanless and Tagett (1989) near the outflow of the C-111 canal. Manatee Bay is connected to the Biscayne Bay hydrologic system. The C-111 canal was completed in the 1960s and its outflow has a large impact on Manatee Bay salinity (Light and Dineen, 1994; Ishman *et al.*, 1998). Core MB-1 penetrates about 106 cm. The upper 85–90 cm are carbonate muds; the lowermost 36 cm are a peat and peaty-shelly marl containing limnic and oligohaline microfaunas (Ishman *et al.*, 1998).

The Taylor Slough core (T-24) is located in Little Madeira Bay, a region sensitive to changes in outflow from Taylor Slough, which drains the southeastern part of the Everglades. Like the Manatee Bay core, T-24 does not have a isotopic age model, although the faunal patterns suggest that salinity-related changes occurred in this region over what is believed to be the past century or so of sedimentation based on the first stratigraphic appearance of *Casuarina* (Ishman *et al.*, 1998).

The seven cores cover a wide range of salinities that vary over monthly and interannual timescales. For example, Halley *et al.* (1995) showed that in June 1995, during a period of relatively low fresh water flow and rainfall, salinities were high ranging from ~25 ppt at Taylor and Manatee Bay to >36 ppt at Whipray Basin. Conversely, in August 1995, during an apparently wet period with higher fresh water flows, salinity ranged

from 4–5 ppt at Taylor Creek to 30 ppt at Whipray. Even larger historical swings in salinity described by McIvor *et al.* (1994) are likely to be a factor in interpreting paleoecological records.

Florida Bay sediments consist mostly of unconsolidated muds containing abundant macro- and micro-fossils. Following lithological description and X-ray radiography, sediments were sampled every 2 centimeters for ^{210}Pb dating and micropaleontological analysis. Approximately 20–40 g of dry sediment was washed through 63 μm sieves and ostracodes in the size fraction >150 and 850 μm were picked with a fine brush. This size fraction yields adults and several juvenile molt stages of essentially all major species living in Florida Bay; our focus here is on trends in epiphytal species.

OSTRACODE SPECIES CENSUS DATA

The counts of key ostracode species from the modern vegetation and sediment samples are given in Table 2 with the major seagrasses and/or macro-benthic algae genera found at each site. Appendix 1 contains the species counts for the seven sediment cores.

NOTE ABOUT OSTRACODE TAPHONOMY

There are four lines of taphonomic evidence suggesting there is minimal transport of ostracode valves at the studied sites. First, the size of adult ostracode valves and carapaces (a carapace consists of two articulated valves held together after death by a tooth-and socket hingement) are too large to have been transported large distances in Florida Bay. Halley *et al.* (1997) showed that most mudbank sediment >~63 μm is autochthonous within a mudbank. Depending on the species, adult ostracode valves and carapaces are >180 μm in length and thus, most adults are in the size fraction of sediment that is not transported. Second, juvenile valves representing 1 to 4 molt stages prior to the adult molt are commonly associated with conspecific adult valves and carapaces. Although time constraints precluded detailed analyses of species' population structure, these qualitative observations indicate most species are represented by juvenile and adult individuals. Third, articulated ostracodes carapaces are common in mudbank sediments and such preservation would not be expected had the ostracodes been transported by currents which tend to disarticulate the carapace. Fourth, fossil assemblages consist of ecologically compatible species; there is no faunal evidence for transport of allochthonous species from other parts of Florida Bay or adjacent habitats. In sum, ostracode taphonomy indicates that the majority of ostracodes examined in this study from the >63 μm size

fraction represent individuals that lived, died and were buried at the mudbank.

STATISTICAL METHODS

We used the changing proportions (also called relative abundances) of ecologically significant indicator species to infer past environmental changes. In paleoecological research, the number of individuals of a particular species n_i is often expressed as

$$\sum_{i=1}^S n_i = n$$

where S is all species in the assemblage and n is the total number of individuals in the sample (see Buzas, 1990). The proportion of a species is expressed as $p = n_i/n$, and p has certain confidence limits that depend on both the value of p for that species and on the value n . Because n , the abundance of ostracodes, varies within each core and among cores, and because picking microfossils is so time intensive, it is important to consider what values of n ensure statistical reliability of species' proportions and still yield meaningful temporal patterns. Ideally, the confidence limits for any given p value should not exceed the observed down-core temporal changes in p if trends and oscillations in p are to be considered meaningful.

Confidence limits on species' proportions are often expressed in paleoecology using the binomial distribution (*e.g.*, Patterson and Fishbein, 1989; Buzas, 1990) as follows:

$$\sigma = (pq/n)^{1/2}$$

where σ = the binomial standard error, $p = n_i/n$, or the proportion of the i^{th} species, $q = 1 - p$. The confidence limits d are expressed as:

$$d = \pm t\sigma$$

where t corresponds to the chosen level of confidence (*i.e.*, $t = 1.96$ for 0.95 confidence).

Table 3 illustrates the different confidence limits d , for three values of n , 100, 200, 300 and 1000 individuals. We see that for a species that comprises 10% of an assemblage ($p = 0.1$), d decreases progressively with increasing sample size (n) from 5.9% (100 individuals), 4.2% (200 individuals) and 3.4% (300 individuals). For a dominant species comprising 50% of an assemblage, the comparable values are higher, 9.8%, 6.9% and 5.7% respectively. The values of d are essentially meaningless for very rare species ($p < 1\%$, Buzas, 1990).

In general, the results presented below for Florida Bay suggest that the long-term variability in indicator species proportions (p) often exceeds the confidence limits (d) imposed by total abundance (n). Thus, we

Table 3.—Confidence limits for 100, 200 and 300 individuals at different relative frequencies.

<i>p</i>	<i>q</i>	<i>n</i>	sigma	<i>t</i>	<i>d</i>
0.1	0.9	100	0.03	1.96	0.0588
0.2	0.8	100	0.04	1.96	0.0784
0.3	0.7	100	0.04582576	1.96	0.08981848
0.4	0.6	100	0.04898979	1.96	0.09602
0.5	0.5	100	0.05	1.96	0.098
0.6	0.4	100	0.04898979	1.96	0.09602
0.7	0.3	100	0.04582576	1.96	0.08981848
0.8	0.2	100	0.04	1.96	0.0784
0.9	0.1	100	0.03	1.96	0.0588
0.1	0.9	200	0.0212132	1.96	0.04157788
0.2	0.8	200	0.02828427	1.96	0.05543717
0.3	0.7	200	0.0324037	1.96	0.06351126
0.4	0.6	200	0.03464102	1.96	0.06789639
0.5	0.5	200	0.03535534	1.96	0.06929646
0.6	0.4	200	0.03464102	1.96	0.06789639
0.7	0.3	200	0.0324037	1.96	0.06351126
0.8	0.2	200	0.02828427	1.96	0.05543717
0.9	0.1	200	0.0212132	1.96	0.04157788
0.1	0.9	300	0.01732051	1.96	0.0339482
0.2	0.8	300	0.02309401	1.96	0.04526426
0.3	0.7	300	0.02645751	1.96	0.05185673
0.4	0.6	300	0.02828427	1.96	0.05543717
0.5	0.5	300	0.02886751	1.96	0.05658033
0.6	0.4	300	0.02828427	1.96	0.05543717
0.7	0.3	300	0.02645751	1.96	0.05185673
0.8	0.2	300	0.02309401	1.96	0.04526426
0.9	0.1	300	0.01732051	1.96	0.0339482
0.1	0.9	1000	0.00948683	1.96	0.01859419
0.2	0.8	1000	0.01264911	1.96	0.02479226
0.3	0.7	1000	0.01449138	1.96	0.0284031
0.4	0.6	1000	0.01549193	1.96	0.03036419
0.5	0.5	1000	0.01581139	1.96	0.03099032
0.6	0.4	1000	0.01549193	1.96	0.03036419
0.7	0.3	1000	0.01449138	1.96	0.0284031
0.8	0.2	1000	0.01264911	1.96	0.02479226
0.9	0.1	1000	0.00948683	1.96	0.01859419

p = proportion of species; *n* = number of individuals, sigma = standard error, *t* = level of confidence, *d* = c.

chose to obtain 100 individual valves and/or carapaces from each 2-cm interval (except in the Park Key core, where we picked 300 individuals) to determine decadal and sub-decadal faunal trends across a wide area of Florida Bay. We were able to obtain about 100 individuals ± 20 from most samples, with the important exception of the interval 72–134 cm in Bob Allen core where there were usually less than 10 individuals. Trends from this low abundance zone are interpreted with caution.

TIME SERIES ANALYSES

We examined trends in *L. matagordensis* at Russell Bank and compared them to trends in the Southern Oscillation index (SOI, a measure of strength of El Niño-Southern Oscillation) using time series analysis.

For time series analysis, the age of each data point was estimated by linear interpolation between dated depths. We then interpolated the *Loxoconcha* and SOI records at constant 1-year intervals. Both records were separated into pre-1940 and post-1940 segments. All segments were linearly detrended and the auto and cross correlation functions for pre-1940 and post-1940 calculated. From these functions the coherency and phase functions were calculated.

DATING AND CORRELATION METHODS

Isotopic dating by ^{210}Pb and ^{137}Cs was carried out by Robbins *et al.* (2000) to obtain age models for the Bob Allen and Russell Bank cores (see also Holmes *et al.*, 2000). These investigators found that Bob Allen and Russell Bank cores BA-6-A and R-19-B have linear sediment accumulation rates of 0.75–1.04 and 1.22 cm yr⁻¹ respectively, for the period covering approximately the last 100–150 years. Park Key has an average accumulation rate of about 0.78 cm yr⁻¹ and the 86-cm core represents approximately the last 100 years. Sediment accumulation at Whipray was much slower and there is an uncorrected radiocarbon age of ~3000 yr BP near the base.

The age model for the Manatee Bay core is not as well established because ^{210}Pb dating was unsuccessful for unknown reasons (see Ishman *et al.*, 1998). However, a pollen age marker, the first appearance datum (FAD) of the genus *Casuarina* between 60 and 70 cm, suggests a maximum age for this interval at ~1890 and a probable age of 1920–1930, a time when this genus became abundant in South Florida (D. A. Willard, personal communication). Similarly, the *Casuarina* FAD in the Russell Key core lies between 94–104 cm, a level consistent with the isotopic age model.

TAXONOMIC AND ECOLOGICAL NOTES

There is considerable taxonomic and ecological data on living ostracode populations collected from coastal bays and estuaries along the Atlantic and Gulf coasts. These include studies of Texas (Swain, 1955; King and Kornicker, 1970; Garbett and Maddocks, 1978) and Campeche, Mexico (Morales, 1966) lagoons; Bahaman (Kornicker, 1961, 1963), Veracruz (Krutak, 1982), and Belize carbonate platforms (Teeter, 1975); mangroves of southwest Florida (Keyser, 1975, 1976, 1977); the continental shelf off west Florida (Puri and Hulings, 1957; Benson and Colman, 1963; Hulings and Puri, 1964) and Florida Bay and other regions off western Florida (Puri, 1960), the Cape Romano region, northwest Florida (Benda and Puri, 1962); the Caribbean and Gulf of Mexico (Maddocks, 1975), and the Atlantic coast (Cronin, 1979).

Species were identified following the taxonomy of

Keyser (1976), Hazel (1983), Cronin (1979, 1990), and Garbett and Maddocks (1978). In Florida Bay sediment *Malzella floridana* (Benson and Coleman 1963) is synonymous with *Radimella floridana littoralis* Grossman 1965 of Keyser (1976) and King and Kornicker (1970). *Loxoconcha matagordensis* Swain 1955 is a widespread epiphytal species living along the Atlantic and Gulf coasts. *Xestoleberis* spp. includes 3 to 4 species that were not distinguished from one another because it is difficult to identify species of *Xestoleberis* based solely on carapace features. *Peratocytheridea setipunctata* is conspecific with *Haplocytheridea setipunctata* of some authors (see Hazel, 1983).

SUBSTRATE AND MUDBANK STRATIGRAPHY

Substrate is an important factor controlling the distribution and abundance of organisms throughout Florida Bay. Substrate types are generally divided into unconsolidated carbonate muds, hard bottoms (mostly in southern Florida Bay), mangrove islands (<2% of the Bay), and seagrass "meadows." Seagrasses, which provide an important Florida Bay microhabitat for many species (e.g., Sheridan 1997), constitute an integral component of mudbanks in the central part of the bay in that they stabilize and help build up the banks (Wanless and Tagett, 1989). The most important types of seagrass species in Florida Bay are: *Thalassia testudinum* (turtlegrass), *Halodule* (shoal grass), *Syringodium* (manatee grass), and *Ruppia* (Widgeon grass) (Robblee *et al.*, 1991). There are also numerous species of marine algae living in Florida Bay, which provide habitat for ostracodes.

Seagrasses play an important role in sedimentation on mudbanks in several ways. Wanless and Tagett (1989) reported that broad-bladed *Thalassia* tend to baffle wave and currents, an attribute that permits fine-grained sediment to accumulate. *Thalassia* rhizome mats also stabilize substrate. Swart and Kramer (1997) reviewed evidence that many organisms, primarily red algae and serpulid worms, and, to a lesser extent, mollusks, foraminifers and other organisms, encrust on *Thalassia* such that when seagrasses die, this carbonate material makes a large contribution to the total carbonate production of the bay. In addition, Halley *et al.* (1997) observed that, although seagrasses are rare-to-absent in many mudbank sediment cores, seagrasses may still have been present when "grassless" deposits accumulated if those grasses had been living upstream of the core site. While this remains a tenable hypothesis at the local scale of mudbanks, our data on phytal ostracode species presented below suggest that over the last century, widespread changes in seagrass abundance have occurred.

RESULTS

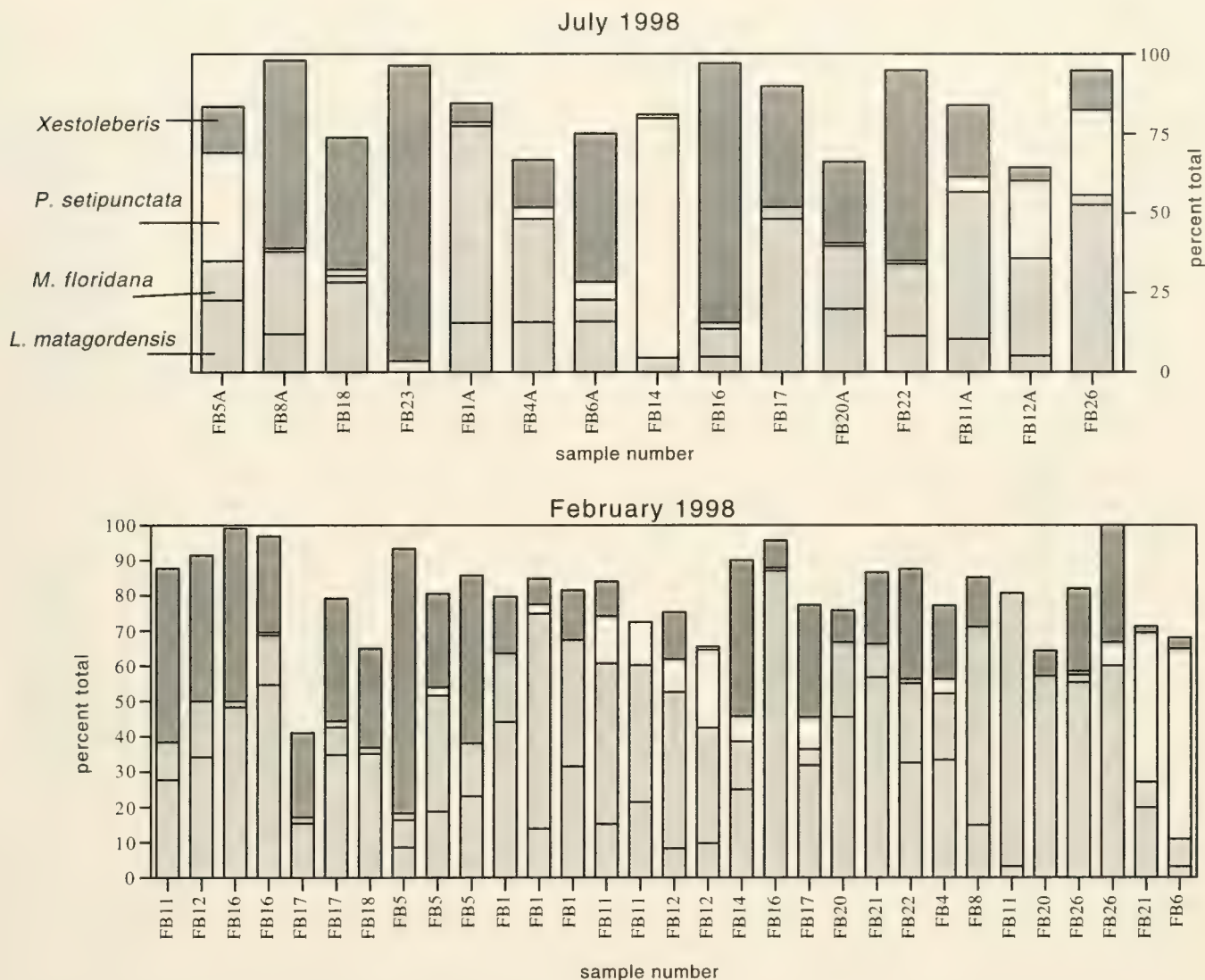
EPIPHYTAL OSTRACODE SPECIES IN MODERN FLORIDA BAY

Vegetation and Substrate

Many ostracode species are adapted to inhabit specific substrates such as seagrasses and sandy bottoms. Text-figure 2 presents data on the four ostracode taxa from Florida Bay stations collected in February and July 1998. For February and July samples, *L. matagordensis*, *M. floridana*, and *Xestoleberis* spp. account for a combined total of 74.5% and 70.9% of the total assemblages, respectively. Two notable exceptions are one sample from FB21 and one from FB6 from February 1998, which are shelly substrate covering soft mud with sparse *Halodule*. These two samples contained abundant *P. setipunctata*. Another exception is the abundance of *P. setipunctata* at sample FB-14. Of the total 2,658 individuals collected from 36 marine algae and seagrass samples during February 1998, 808 (30.4%) were *L. matagordensis*, 668 (25.1%) were *Xestoleberis* spp., 614 (23.1%) were *M. floridana*, and only 91 (3.4%) were *P. setipunctata*. Of 1,379 total individuals obtained from 15 samples in July 1998, 248 (18%) were *L. matagordensis*, 274 (19.9%) were *M. floridana*, 173 (12.5%) were *P. setipunctata*, and 442 (32.1%) were *Xestoleberis* spp.

Text-figures 3 and 4 compare the relative frequencies of these four taxa by season and by vegetation type. The relative frequencies of ostracode taxa living on macro-benthic algae, and the seagrasses *Thalassia* and *Halodule* are generally similar in both February and July collections, except that *L. matagordensis* is relatively more abundant on algae during February, and both *L. matagordensis* and *M. floridana* are more common on *Thalassia* in February. The species composition of ostracode assemblages on *Halodule* is very similar during both months. *Xestoleberis* spp. predominates on marine algae in both February and July samples. In general, these data show that *L. matagordensis* and *M. floridana* are characteristic epiphytal species living on Florida Bay seagrasses (*Thalassia*, *Halodule*), and that *Xestoleberis* spp. prefer macro-benthic algal habitats. *P. setipunctata* is most common in samples with *Halodule*, a pattern that may be an artifact of the sampling of *Halodule*. *Halodule* is typically found on very soft substrates, therefore root material and adhering mud is often collected with the grass sample.

These results confirm those of earlier studies that *L. matagordensis* (Tressler and Smith, 1948; Swain, 1955; Morales, 1966) and related species (i.e., *Loxoconcha japonica*, Kamiya 1988; *L. fischeri*, Teeter 1975) prefer mainly phythal habitats. Our evidence that

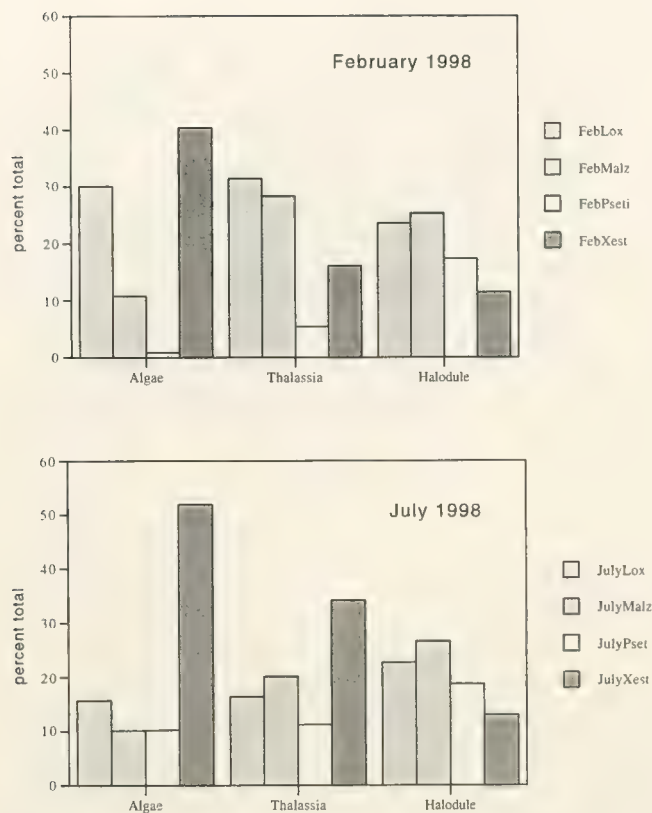


Text-figure 2.—Proportion of four ostracode taxa in modern Florida Bay samples collected in July and February 1998 (see Text-figure 1 for sample locations). Grey = *Loxococoncha matagordensis*, hatchured = *Malzella floridana*, white = *Peratocytheridea setipunctata*, rectangles = *Xestoleberis* spp.

many species of *Xestoleberis* prefer macro-benthic algal habitats also confirms earlier findings of other ostracode ecologists about the preference of tropical and subtropical species of *Xestoleberis* for marine algae. For example, Teeter (1975) found seven *Xestoleberis* species were common in carbonate platform assemblages from Belize where macro-benthic algae was common. Teeter also reported that several of the species of *Xestoleberis* from Belize also lived in Florida Bay. Hartmann (1981, 1984) found *Xestoleberis* often preferred to live on marine algae in lagoons in the Society Islands, Taumoto and at Heron Island off eastern Australia.

In contrast to these phytal species, *Peratocytheridea*

setipunctata is known as a predominantly sediment-dwelling species in Pamlico Sound, North Carolina (Grossman, 1965) and in Chincoteague Bay, Virginia (Cronin unpublished data). Our findings confirm that this species prefers (average 48.5%) shelly substrates and it also suggests that in Florida Bay it inhabits areas of *Halodule* dominance. Throughout its geographic range, *P. setipunctata* usually lives in habitats with little or no *Zostera*, *Thalassia*, or marine algae. Although we do not present the data here, other species associated with *P. setipunctata* in Florida Bay also typically inhabit sandy substrates devoid of vegetation. These include *Proteoconcha* spp., *Acuticythereis laevissima*, and *Reticulocythereis floridana*.



Relative Abundance of Four Ostracodes on Florida Bay Marine Algae, *Thalassia*, and *Halodule*

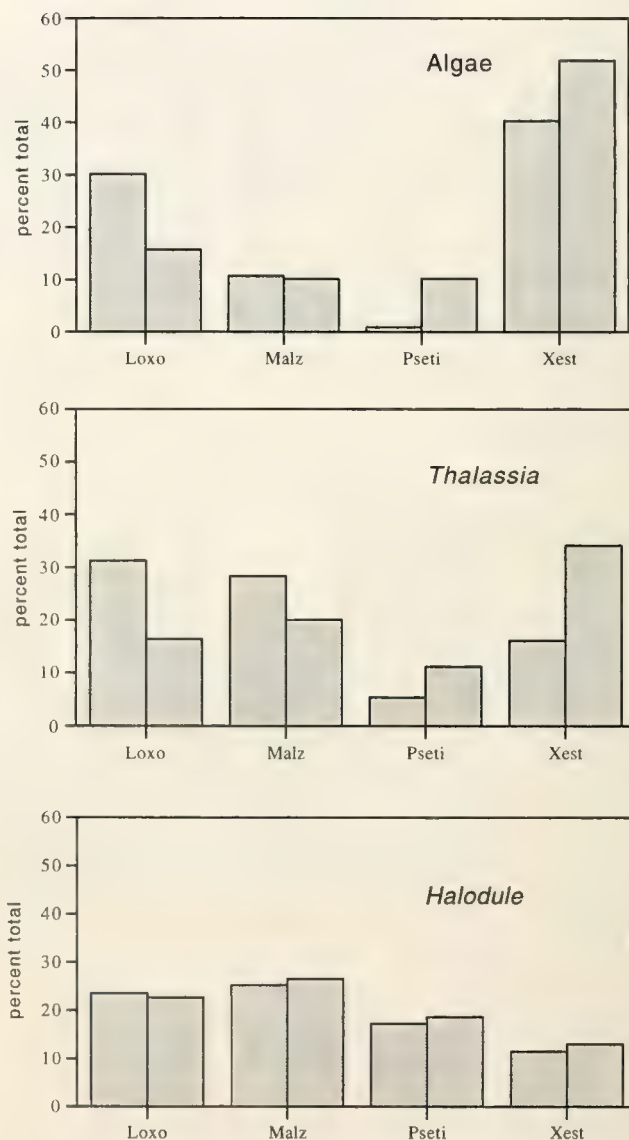
Text-figure 3.—Proportion of four ostracode taxa from modern Florida Bay samples plotted by season and vegetation type.

Salinity and Temperature

In addition to their preference for particular vegetation and substrate types, it is important to establish if temperature and/or salinity constrain the distribution of ostracode species within Florida Bay. Text-figure 5 presents species' relative frequency data plotted against the July and February salinity and temperature measured at each site by Dr. Lynn Brewster-Wingard. These data show that *L. matagordensis*, *M. floridana*, *P. setipunctata* and *Xestoleberis* spp. all are able to inhabit polyhaline to euhaline conditions (15–35 ppt) and water temperatures from ~20 to 35°C. These findings support those of earlier ecological studies of ostracodes from southwest Florida by Keyser (1975, 1977). For example, some species of *Xestoleberis* (i.e., *X. mixohalina*) are able to tolerate fluctuating salinities and periods of hyper- and hypo-salinity (Hulings and Puri, 1964).

The plots in Text-figure 5 also show that there are no apparent relationships between the relative frequen-

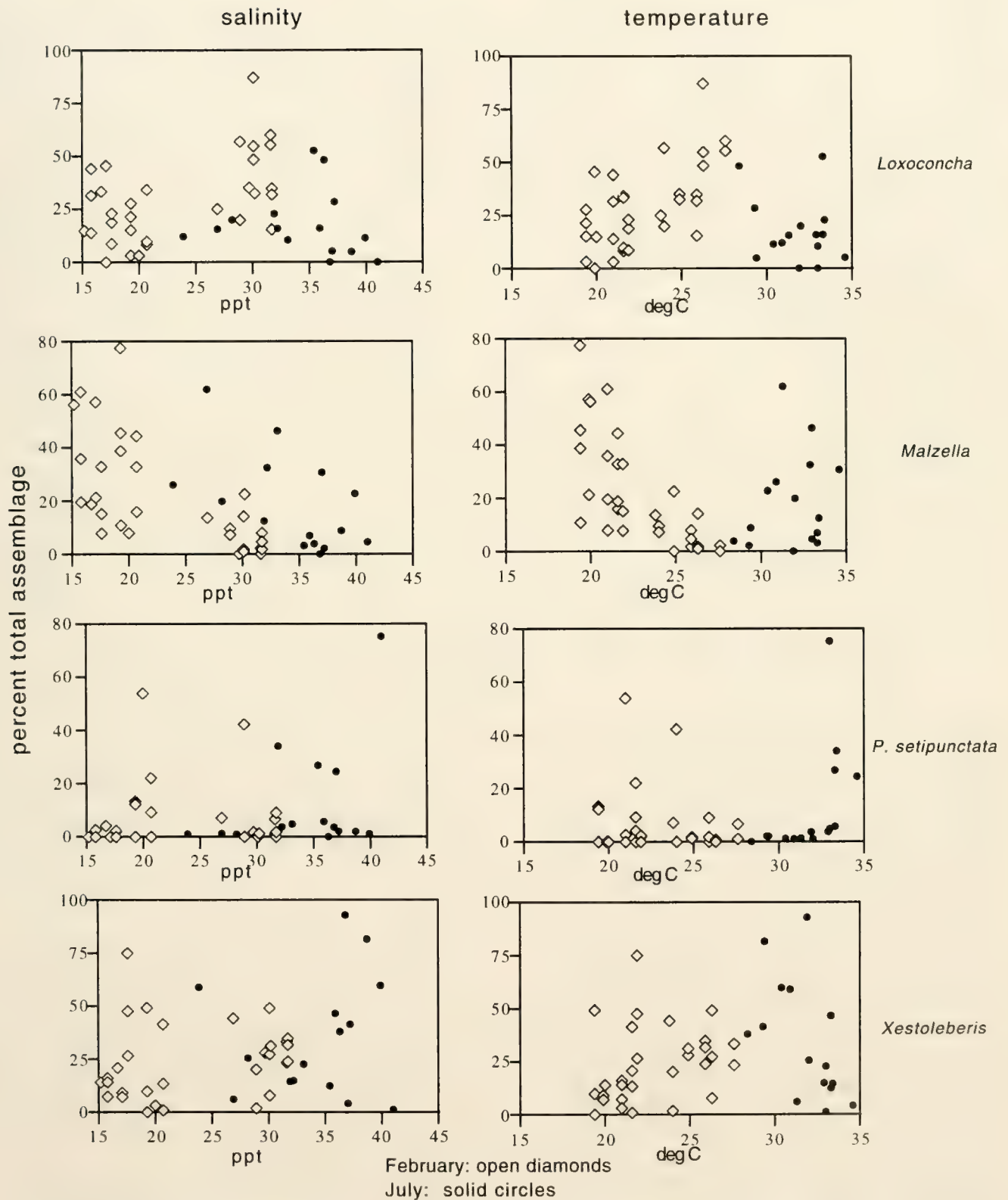
Ostracode Taxa Feb vs July grouped by Vegetation Type



Text-figure 4.—Proportion of four ostracode taxa from modern Florida Bay samples plotted by vegetation type.

cies of ostracode taxa and temperature or salinity across the range of temperature and salinity sampled. Two possible exceptions are that *M. floridana* seems to be more abundant in cooler winter water temperatures of 20–22°C and 31–35°C and *L. matagordensis* is common (>25%) at winter temperatures of 19–27°C. These may reflect different seasonal life histories for these two species, allowing them to inhabit the same epiphytal habitat on *Thalassia*. King and Kornicker (1970) found a similar relationship as they documented seasonal changes in the relative abundance of

Florida Bay Ostracode Taxa: Salinity and Temperature Relationships



Text-figure 5.—Relationships between temperature and salinity and four ostracode taxa based on 1998 collections from Florida Bay.

M. floridana and *L. matagordensis* in Texas Bays and lagoons.

M. floridana also seems to be relatively common at salinities between 15–20 ppt. However, King and Kornicker (1970) studied the seasonal ecology of *M. floridana* and demonstrated that this species dominated assemblages from Texas lagoons during the summer months when salinity often exceeded 35–40 ppt. Thus, *M. floridana* is a euryhaline species tolerating a wide range of salinities. The relationship of Florida Bay ostracodes to salinity and its application to reconstruction of salinity history will be treated in a separate study.

In summary, it must be emphasized that multiple environmental factors including, but not limited to, substrate, salinity, and temperature, ultimately determine the relative proportion of various ostracode species in any assemblage. There is nonetheless compelling ecological evidence on Atlantic and Gulf Coast ostracodes, accumulated over several decades of research, in various marginal marine settings, and in the new analyses presented above, that certain ostracode species have preferences for phytal habitats. This habitat preference makes *M. floridana*, *L. matagordensis* and *Xestoleberis* spp. potentially valuable paleoecological “proxy” indicators of changes in the relative abundance of subaquatic vegetation in Florida Bay when they are studied in well-dated sediment cores.

HISTORICAL TRENDS IN EPIPHYTAL OSTRACODES

Florida Bay Mud Island Stratigraphy and Sedimentation

The stratigraphy, sedimentation, and microfaunal taphonomy of Florida Bay mudbanks make them excellent sedimentary environments in which to study the paleoecology of Florida Bay. Before discussing historical trends in ostracodes, we briefly describe some important attributes of mudbank geology and paleontology based on papers by Enos and Perkins (1977, 1979), Wanless and Tagett (1989) and Swart and Kramer (1997) and references therein.

Florida Bay is divided into semi-isolated, shallow (usually <1 to 2 m) sub-basins separated from each other by small, partially emergent islands barely exposed during low tide. These islands are called mudbanks (Enos and Perkins, 1979; Wanless and Tagett, 1989). “Mud island” is the term given to the small surfaces that sit on top of, or on the flanks of mudbanks. There are more than 200 mud islands in Florida Bay; they consist mostly of fine-grained carbonate mud whose internal stratigraphy and abundant microfossils make them amenable to isotopic dating and paleoecological analysis (Wanless and Tagett, 1989; Swart and Kramer, 1997; Robbins *et al.*, 2000).

Understanding sedimentary processes in Florida Bay in general, and on mudbanks, in particular, is critical for establishing faunal and ecosystem trends from sediment cores. Holocene sediment blankets the floor of Florida Bay forming a thin veneer covering the limestone “bedrock” consisting of the late Pleistocene Miami Limestone. These sediments consist of about 95% unconsolidated carbonate derived mainly from biogenic skeletal material from serpulids, calcareous algae, foraminifers, coelenterates, ostracodes, mollusks, and other organisms (Enos and Perkins, 1977; Nelson and Ginsberg, 1986). Most sediments that form the mudbanks are classified as bioturbated pelloidal and molluscan wackestones and/or mudstones (Enos and Perkins, 1979).

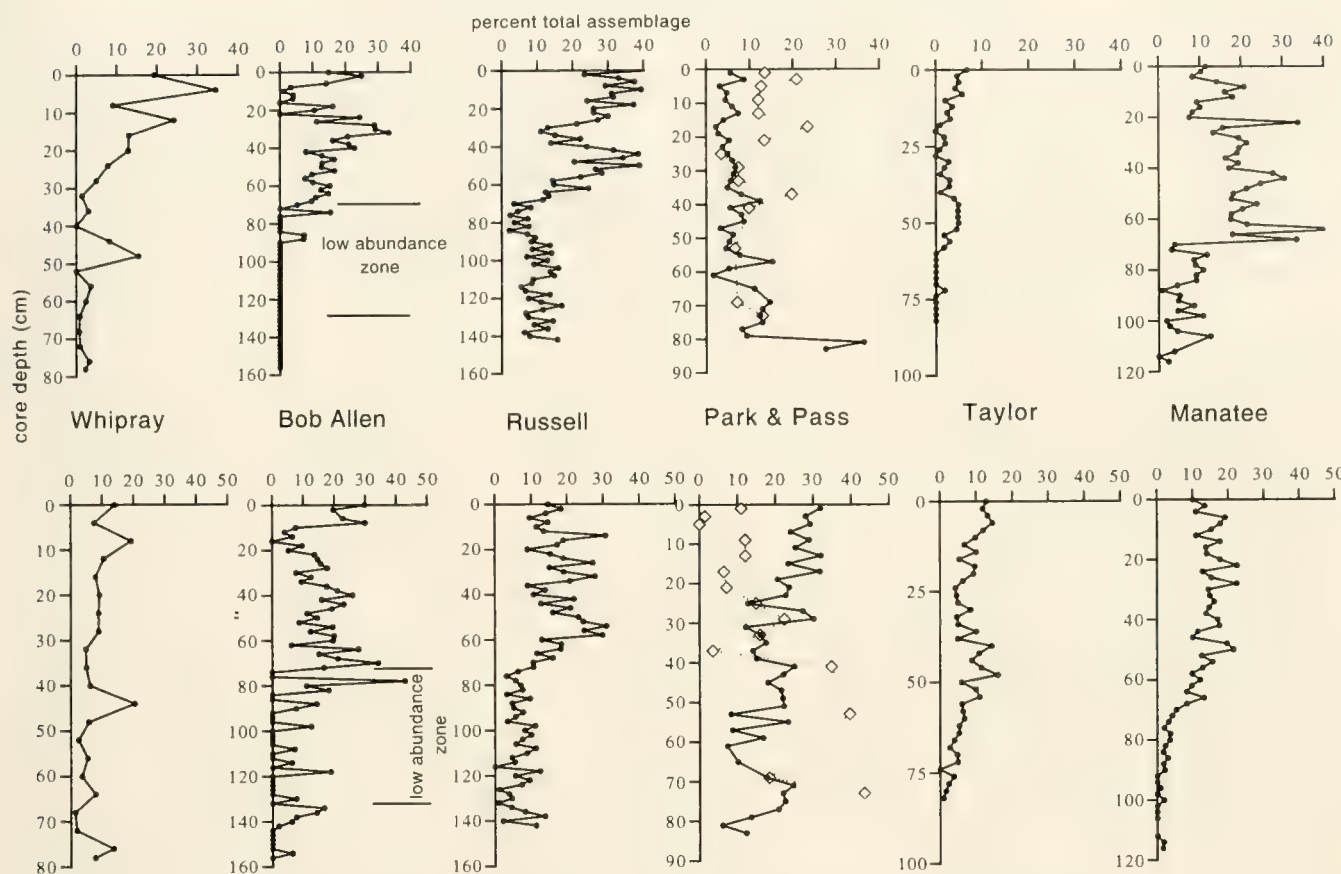
In their review of the origin and stratigraphy of mudbanks, Wanless and Tagett (1989) classified Florida Bay mudbanks into four categories reflecting bank morphology, stratigraphy, sedimentology and bank dynamics. In the “Central Migration Zone” of Florida Bay, where the Bob Allen, Russell, and Park Keys are located, sedimentary processes that form mudbanks are generally dominated by erosion on the windward side and deposition on the leeward side. These processes produce features that have a history of migration that is dependent on the predominant winds, sediment supply and wave energy (Enos and Perkins, 1979; Wanless and Tagett, 1989). Although mudbank sediments are often bioturbated, in some cases they consist of finely laminated muds suggesting little or no bioturbation. Stratigraphic and isotopic studies also indicate that some mudbanks have experienced relatively high rates of fairly continuous sedimentation over the past few centuries (Holmes *et al.*, 1997).

The provenance of mudbank sediments is also important in determining the significance of faunal and paleoecological trends. Halley *et al.* (1997) concluded on the basis of bomb-produced radiocarbon analyses that mudbank sediment coarser than 250 μm is not transported, sediment between 63 and 250 μm is sometimes transported, and sediment finer than 63 μm is almost all transported.

In sum, the stratigraphy and sedimentation of Florida mudbanks is relatively well known, sediment accumulation rates are high and provide interdecadal temporal resolution, and adult and most juvenile ostracodes studied from the >150 μm size fraction are not transported (smaller juveniles are more likely to have been transported), and abundant. These attributes make paleoecological study of Florida Bay a viable means to reconstruct the history of Florida Bay.

Trends in Epiphytal Species

Text-figures 6 and 7 show changes in relative frequencies of the four indicator ostracode taxa in seven

a. Downcore Trends in *Xestoleberis* in Florida Bayb. Downcore trends in *Loxoconcha matagordensis* in Florida Bay

Text-figure 6.—Plot of relative frequencies of *Xestoleberis* (6a top) and *L. matagordensis* (6b, bottom) for seven cores. Park Key core is solid line, Pass Key core is dotted line.

cores from Whipray, Bob Allen, Russell, Park, Pass, Taylor, and Manatee Bay, plotted against core depth. Several stratigraphic trends are evident from these records:

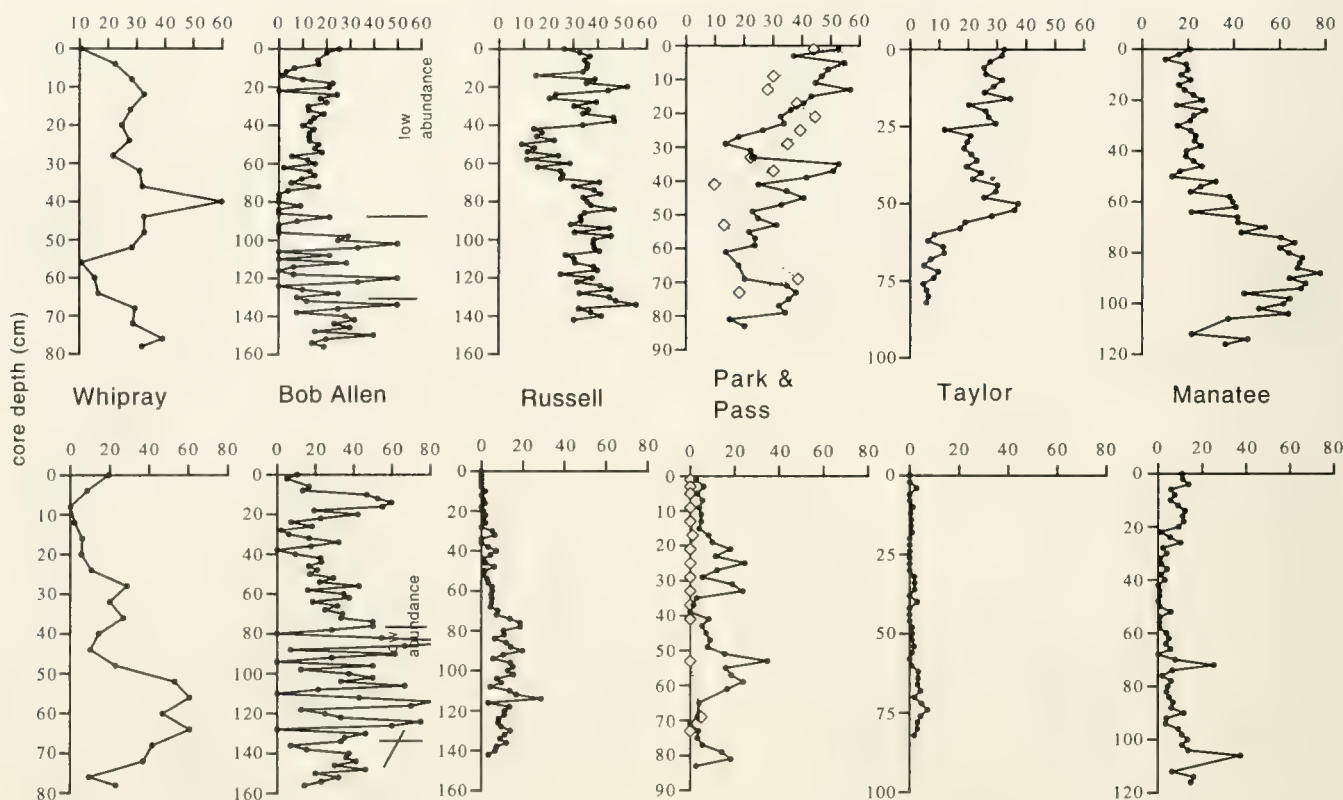
1. All cores except that from Park Key show increases in the proportions of *Xestoleberis* from 0 to 10% in the lower intervals of the cores to 20–40% in upper intervals (Text-fig. 6a).
2. All cores except Pass Key show increases in the proportions of *L. matagordensis* from 0–10% to >10–30% (Text-fig. 6b).
3. Proportions of *M. floridana* oscillate widely in all cores, generally with greater proportions in the upper intervals, except at Manatee Bay where this species declines significantly (Text-fig. 7a).
4. There is a net decline in the proportions of *P. setipunctata* in all cores (Text-fig. 7b).

It is also noteworthy that at the Bob Allen and Russell Bank cores, two cores with the most detailed sam-

pling, the first order trends in all four taxa are generally similar, taking into account the artifacts produced by low abundance between 70 and 120 cm at Bob Allen.

The temporal significance of these trends is revealed by plotting the relative frequencies of each species against age derived from the lead-210 dating for five cores from central and eastern Florida Bay (Text-figs. 8–11; Table 1; Holmes *et al.*, 1997). It should be kept in mind that the limitations of the ^{210}Pb dating preclude precise inter-site comparison of interannual trends, especially during periods in the early 20th and late 19th century when the precision of ^{210}Pb dating diminishes. Rather, our objective is to search for synchronicity or asynchronicity in trends in indicator species over inter-decadal timescales.

During the period 1910 through the 20's, *L. matagordensis* (Text-fig. 8) is relatively rare at Russell, Park and Bob Allen, though the Bob Allen core has sparse ostracodes in this interval. All three cores have

a. Downcore Trends in *Malzella floridana* in Florida Bayb. Downcore Trends in *Peratocytheridea setipunctata* in Florida Bay

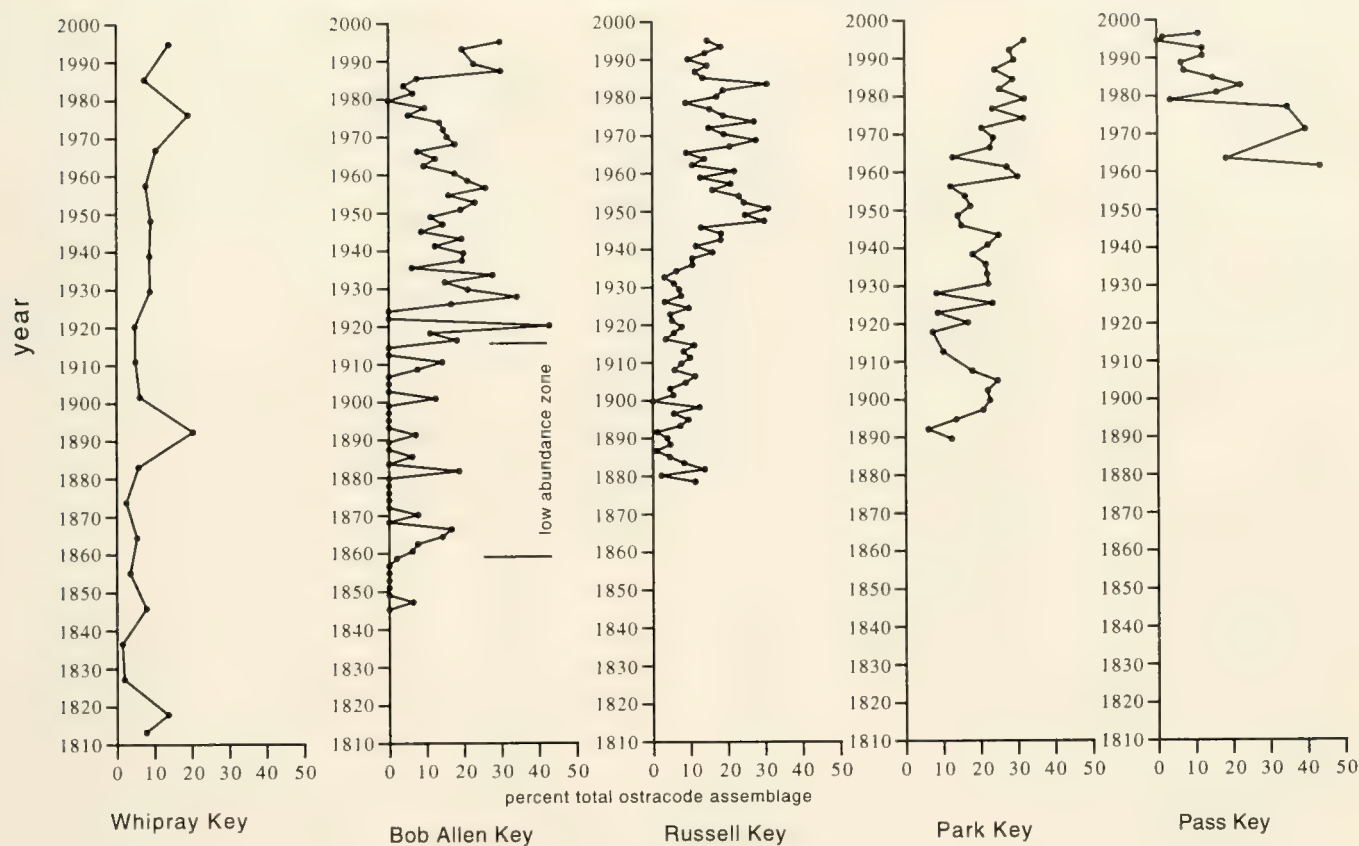
Text-figure 7.—Plot of relative frequencies of *M. floridana* (7a top) and *P. setipunctata* (7b, bottom) for seven cores. Park Key core is solid line, Pass Key core is dotted line.

intervals where this species is relatively common (>20–30%) during the late 1940's through the 1950's. Another epiphytal ostracode species, *Paracytheroma stephensoni* (not shown in figure) is also relatively abundant in the Russell Bank core during this interval. After the 1950's, the abundance of *L. matagordensis* fluctuates at Russell and Bob Allen Keys and shows a gradual increase in abundance at Park Key. Three cores exhibit significant declines in *L. matagordensis* during the late 1970's and early 1980's: Bob Allen (from 20 to 0%), Russell (from 28 to 8%) and Pass Key (from 40 to <10%).

Malzella floridana appears to have been an important member of the assemblage during the late 19th and early 20th centuries at all sites (Text-fig. 9). At Russell Bank, there was a progressive decline in *M. floridana* between 1935 until the late 1950s when this species reaches its lowest percentages. The Russell and Park Key records suggest that following a period of minimum abundance in the 1950's, *M. floridana* became a more abundant part of the ostracode assemblage (~50%) during the 1960's through 1980's. However,

wide swings in its abundance (swings from less than 20% to almost 50%) occur over the past 30 years at all the sites. The most noteworthy pattern is reminiscent of that observed for *L. matagordensis*. Two cores (Russell and Bob Allen) show oscillations in *M. floridana* during post-1960's: Park Key shows a gradual increase of *M. floridana* with minor declines during the 1980's and 1990's, whereas Whipray shows a decline from 35 to ~20% since the 1960's. A decline in *M. floridana* also occurred at Pass Key (from 40 to 10%) during the 1960s and 1970s. In general, these data provide evidence for fluctuating abundances of *M. floridana* including declines during the 1970s and early 1980s at some sites.

An increase in the abundance of *Xestoleberis* (Text-fig. 10) is dated at between the 1920's and 1960's at Whipray, Bob Allen and Russell Keys when *Xestoleberis* rose from less than 10–15% to 30–40%. *Xestoleberis* abundance seems to have peaked during the 1950s and 1960s, declined during the 1970's and the early 1980s, then increased again at all sites except Park Key during the late 1980's and 1990's. Except

Historical Trends in *L. matagordensis* in Florida BayText-figure 8.—Trends in *L. matagordensis* in five cores from Florida Bay.

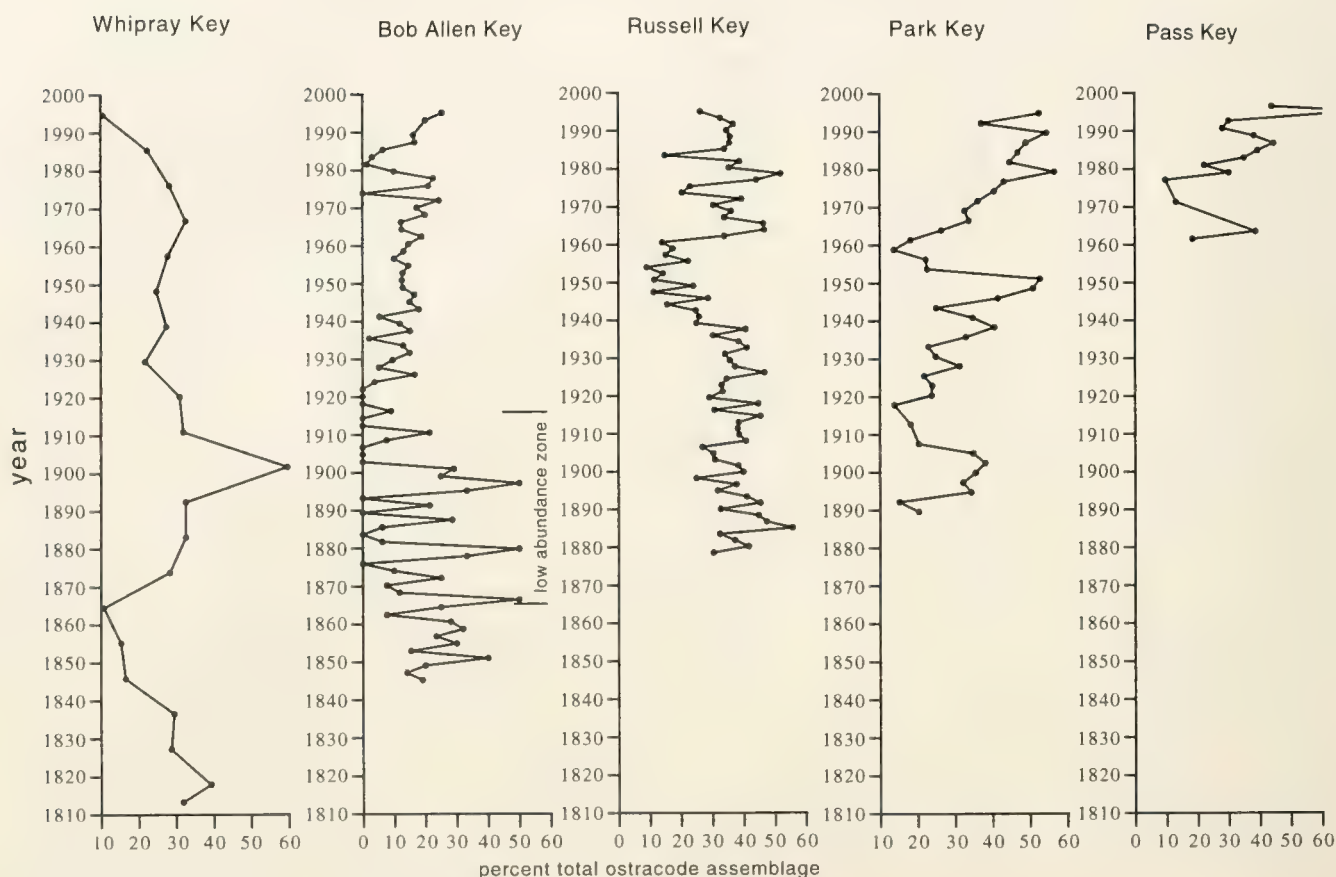
for the two samples dated at around 1890–1900, the abundance of *Xestoleberis* at Park Key remained fairly steady over the past century.

Significant declines in the relative frequencies of *P. setipunctata* (Text-fig. 11) begin in the early 1930s at Whipray, Bob Allen, Russell, and Park Keys and continued, with short reversals at Bob Allen and Park, up through the 1990s. *Reticulocythereis floridana* (not shown), another species that lives on sediment, also declines in abundance from bottom to top of the Russell Bank core. All cores suggest that *P. setipunctata* was a much more important part of the Florida Bay ostracode fauna during the late 19th century and first half of the 20th century than it was during the last half century.

Because both *L. matagordensis* and *M. floridana* have similar ecological requirements in terms of their preference for *Thalassia* as a habitat, we lumped them into a single “*Thalassia*” indicator index and compared the temporal changes in their abundance in the Russell and Park Key cores (Text-fig. 12). These sites are located about eight kilometers apart, both have

abundant ostracodes throughout the core, excellent ²¹⁰Pb chronology and high sediment accumulation rates, and thus should be comparable if the observed trends are typical of the area. The results suggest that prior to ~1920 oscillations in “*Thalassia*” species are out of phase at the two sites, though we cannot exclude the possibility that the age model for the lower parts of these cores is incorrect. After a minimum abundance at both cores around 1920, both cores show the following similar fluctuations in the abundance of these species. After ~1920, there is an increase to 40–50%, then, a peak in abundance ranging from 50% to 65% occurred at Russell and Park respectively ~1936 and 1948, followed by a decline to <40% in the late 1950s, a steep rise in the 1960s, a decline in the 1970s at Russell Key, and an increase to historically the highest levels at times during the late 1970s to the 1990s. Thus, even though *L. matagordensis* and *M. floridana* are known to have different patterns of relative abundance during a single year due to seasonal effects (King and Kornicker, 1970), the first-order decadal patterns since ~1920 are similar at the two sites, sug-

Historical Trends in *M. floridana* in Florida Bay



Text-figure 9.—Trends in *M. floridana* in five cores from Florida Bay.

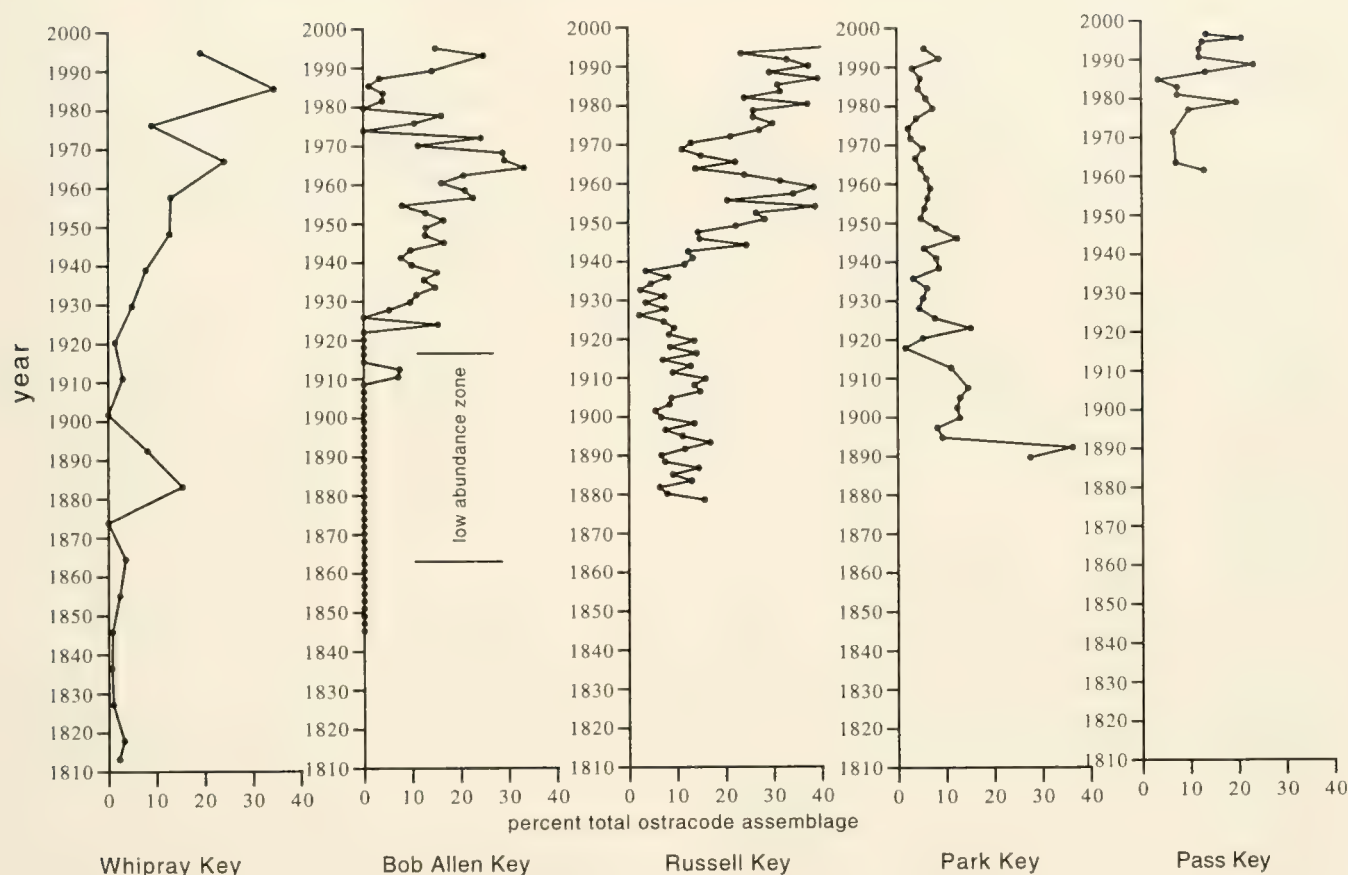
gesting that similar changes in seagrass and algal habitats have occurred.

POSSIBLE CLIMATIC EFFECTS ON FLORIDA BAY EPIPHYTAL OSTRACODES

Environmental factors such as salinity variability caused by climatological and hydrological processes may also contribute to the observed decadal changes in epiphytal ostracodes and their inferred seagrass habitats. Dwyer and Cronin (this volume) demonstrated that the influence of interannual and decadal variability in rainfall, especially during winter season, has a large impact on long-term salinity variability in Florida Bay. Salinity in this portion of Florida Bay can range from lower polyhaline values, <20 ppt, to hypersaline >45–50 ppt. Thus, to examine the possible role of climatological factors on Florida Bay epiphytes, we compared trends in the relative frequency of *L. matagordensis* from the Russell Bank, Park Key and Bob Allen cores with records of winter rainfall in south Florida (Text-fig. 13). We chose this species because it its eco-

logical preference (salinity range is upper mesohaline-polyhaline and epiphyte habitats of *Thalassia* and *Zostera* beds) is well known from numerous studies along the Gulf of Mexico and Atlantic coast of North America (see above).

The trends shown in Text-figure 13 suggest that for most of the past century there is an inverse relationship between winter rainfall and *L. matagordensis* abundance. During wet periods (winter rainfall > 30 cm/yr) such as the 1930s, 1950s and post-1980, *L. matagordensis* is relatively abundant compared to drier periods (winter rainfall < 30 cm/yr) of the 1900–1910, 1915–1925, 1940s, 1960s and 70s. Two notable exceptions occur in the Russell core where during the late 1940s/early 1950s and around 1970, *L. matagordensis* is abundant during periods of low rainfall. A greater abundance of *L. matagordensis*, relative to other more marine species, during periods of wet climate and lower Florida Bay salinity would be expected based on this species' preference for polyhaline conditions.

Historical Trends in *Xestoleberis* in Florida BayText-figure 10.—Trends in *Xestoleberis* in five cores from Florida Bay.

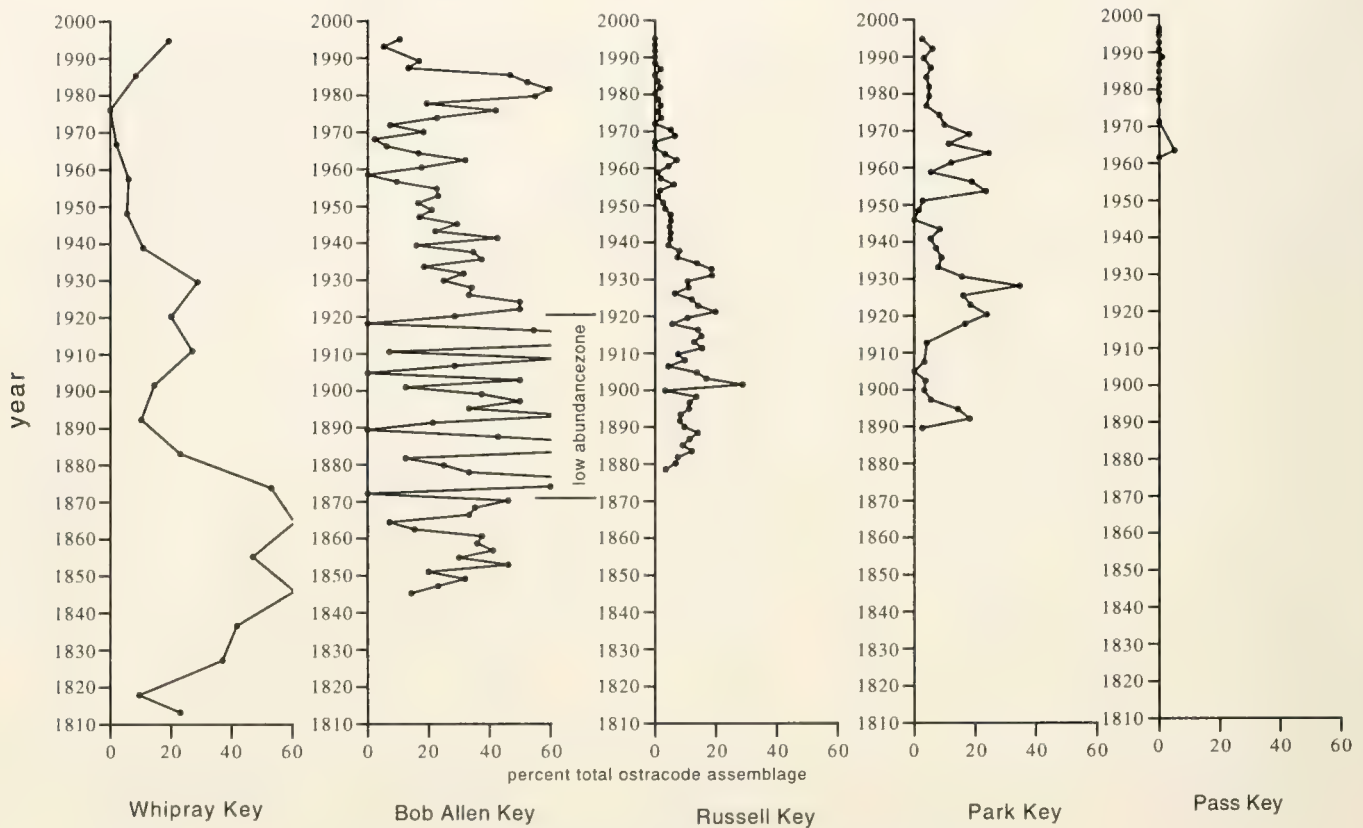
There are two important sources of uncertainty in this analysis. First, it is not clear how rainfall-driven salinity variations might affect the various species of seagrass, especially *Thalassia*, which *L. matagordensis* prefers as its habitat. Salinity is probably influencing both the seagrass habitat of *L. matagordensis* as well as this species ability to reproduce and survive in a particular part of the bay (see Discussion). Second, we assume that there is no “lag” time in the response of populations to large-scale salinity oscillations such as those observed by Robblee *et al.* (1991) and Dwyer and Cronin (this volume) for the past few decades. Nonetheless, the broad patterns suggest that salinity, as well as seagrass availability, is a factor in controlling the abundance of *L. matagordensis* over decadal timescales.

DISCUSSION

The ecological data on ostracodes presented above provide evidence that certain ostracode species are predominantly epiphytal in habitat in modern Florida Bay

and the fossil data show that there have been significant interdecadal changes in their relative frequencies at several localities in central and eastern Florida Bay. The most important issue regarding the interpretation of these interdecadal faunal trends is whether changes at each site represent a local trend at a single mudbank or whether they signify synchronous, regional events that characterized the central and eastern parts of Florida Bay. If these do indeed signify regional changes in Florida Bay benthic habitats, then what are their causes?

It is unlikely that two of the major faunal trends discussed above would occur by chance simultaneously at four or five mudbanks located kilometers apart. The first is the long-term decline in the sediment- and *Halodule*-dwelling *P. setipunctata* coincident with the rise in species that inhabit *Thalassia* and macro-benthic algae (*L. matagordensis*, *M. floridana* and *Xestoleberis* spp.) during the mid-20th century. An increase in epiphytal species is not only evident in central and eastern Florida Bay, but also near the northern tran-

Trends in *P. setipunctata* in Florida BayText-figure 11.—Trends in *P. setipunctata* in five cores from Florida Bay.

sition zone at the Taylor core site and in Manatee Bay, though these sediments are not as well dated as the other sites. Thus, central Florida Bay most likely experienced region-wide benthic habitat changes during the mid-20th century. Moreover, similar synchronous changes in mollusks and benthic foraminifers also occurred in these areas (Brewster-Wingard *et al.*, 1998; Brewster-Wingard and Ishman, 1999).

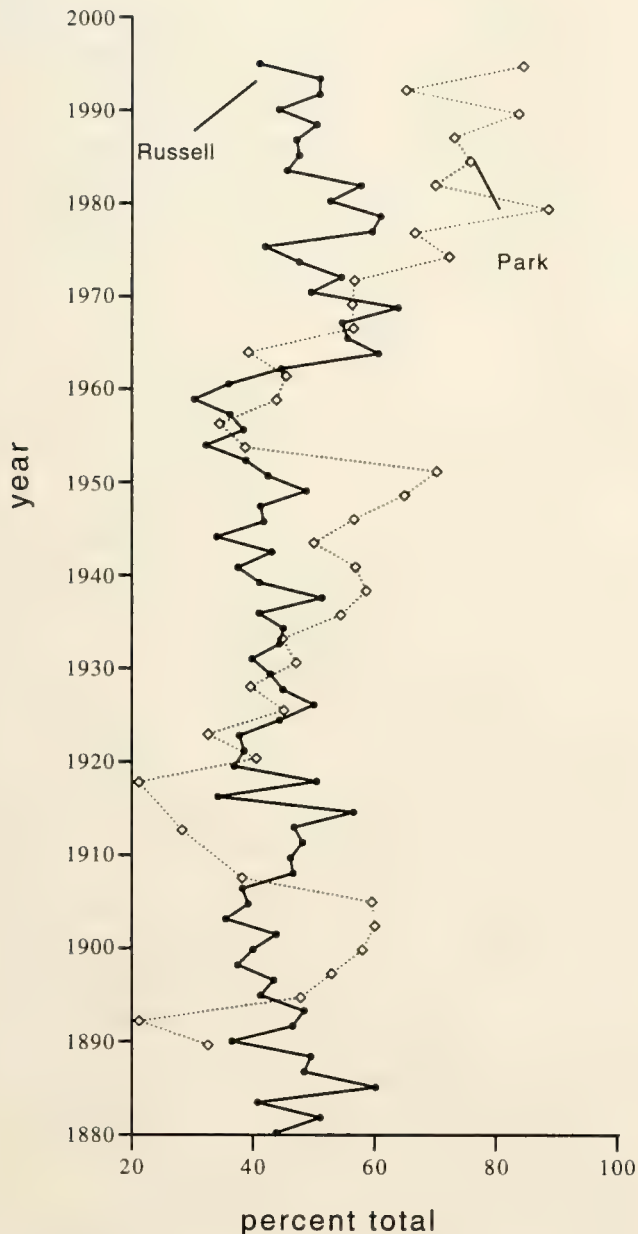
The second event is the decline in seagrass and algal-dwelling ostracodes species during the late 1970s and 1980s. Although the strength of the decline varied by species and by site, the stark contrast between the abundance of epiphytal species during the 1950s and 60s and the very low abundance at times during the following two decades suggests a broad regional shift occurred at this time.

What were the causal factors behind these 20th century changes? Many hypotheses have been proposed to explain the causes of seagrass die-off in the late 1980s, but these theories do not address natural cycles of change in seagrass distribution, and the possibility that seagrass "meadows" were not always as exten-

sive as they were in the early 1980's. The most significant and often cited factors proposed to explain the die-off include changes in salinity (Boesch *et al.*, 1993; Robblee *et al.*, 1991; Eichinger *et al.*, 1998; Blakesley, 1998), light availability (Boesch *et al.*, 1993; Stumpf and Frayer, 1998), water temperature (Robblee *et al.*, 1991; Zieman, *et al.*, 1998), nutrient availability (Lapointe *et al.*, 1994), disease (Blakesley *et al.*, 1998; Boesch *et al.*, 1993; Durako, M. J. and Kuss, 1994; Robblee *et al.*, 1991), eutrophication (Lapointe *et al.*, 1994), and hypoxia of roots (Carlson *et al.*, 1994; Robblee *et al.*, 1991).

One approach to addressing the question of seagrass dieoffs is to first examine what has caused both the build-up of sub-aquatic vegetation beginning around 1950, and the subsequent decline in recent decades. One hypothesis is that this mid-century shift was related to anthropogenic disruption of freshwater flow into Florida Bay, which has been described in papers by Light and Dineen (1994) and McIvor *et al.* (1994). Beginning in 1910 and continuing for the next few decades, canal and levee construction caused the shut-

Trends in seagrass ostracodes at Russell and Park Keys



Text-figure 12.—Plot of summed proportion of *L. matagordensis* and *M. floridana* in Russell Bank and Park Key cores.

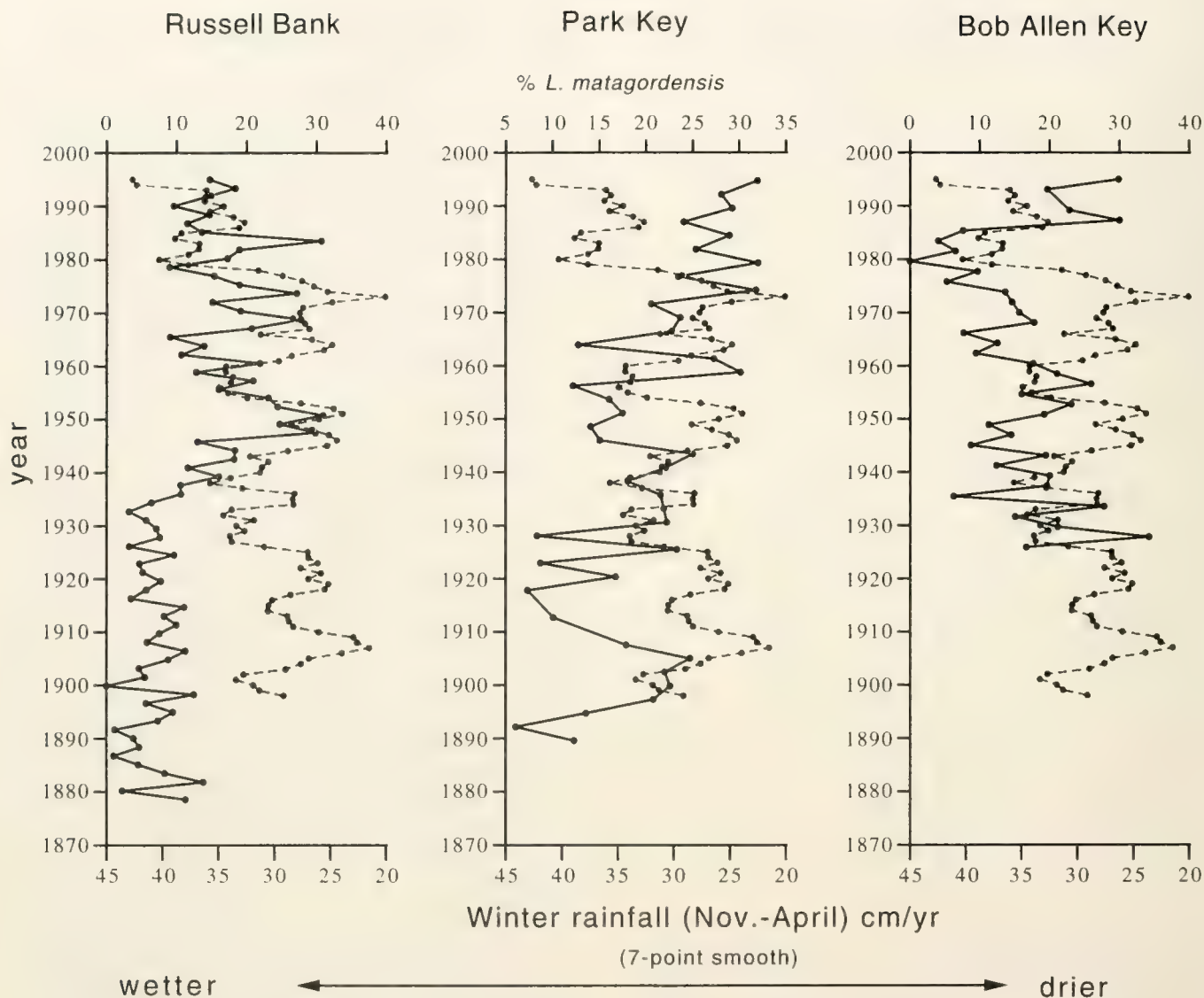
off of freshwater flow southward from Lake Okeechobee diverting it towards the Atlantic Ocean. Smith *et al.* (1989) interpreted the changes in Florida Bay coral fluorescence as a manifestation of these freshwater diversions. It is possible that as a result of these changes to the natural hydrology, Florida Bay has, over the past 5 decades, become more sensitive to variability in

freshwater flow and/or to precipitation, at least compared to the period prior to ~1940.

Another idea is that other anthropogenic events such as the construction of the railway between Miami and Key West disrupted the exchange of water between Florida Bay and the Gulf of Mexico (Swart *et al.*, 1996a). This “railway” hypothesis holds that the 1907–1912 building of the railway restricted circulation, which allowed the products of the oxidation of organic carbon to build up in the bay. This event might, in theory, have also disrupted Florida Bay circulation and natural salinity variability. However, one would have to explain the mid-century faunal shifts preserved in central Florida Bay sediment cores in terms of a lagged faunal response to the completion of the railway.

The decreased frequency of hurricanes since 1948 was also noted by Swart *et al.* (1996a) as a possible explanation for diminished exchange of Florida Bay and Gulf of Mexico water and increased late 20th century eutrophication that was evident from their coral isotope record. It is interesting to speculate that the carbon isotopic excursions recorded by Swart *et al.* may be related to the appearance of seagrasses and algae seen in our core records. It is nonetheless difficult to separate the hurricane influence from that of ENSO (strong El Niño events are correlated with decreased hurricane landfall for the U.S. Atlantic coast, Gray, 1984; O’Brien, 1996) and from the impact of engineering projects in the 1950s and 60s (Swart *et al.*, 1996a).

An alternative hypothesis to explain changes in epiphytial ostracode species might be that, since the 1940’s, climatological factors have caused greater variability in regional precipitation, at least relative to the 19th and early 20th centuries. This “climatic” hypothesis would hold that post-1940 paleoecological variability is related to “natural” changes in the climate system rather than human activities. There is, in fact, considerable evidence that beginning in the mid-1970’s, ENSO has behaved irregularly compared to its behavior over the past few centuries. Trenberth and Hurrell (1994), for example, showed that El Niño episodes became more frequent and La Niña episodes were weaker and less common since 1976. In addition, changes in longer-term climatic variability related to the Pacific-North American (PNA) pattern (Wallace and Gutzler, 1981) also occurred in the mid-1970s. Henderson and Robinson (1994) showed that during certain seasons changes in the PNA index coincided with precipitation variability in the southeastern United States, though they cautioned that south Florida precipitation exhibits patterns quite distinct from those in states to the north.



Text-figure 13.—Plot of relative frequency of *L. matagordensis* at Russell Bank, Park Key and Bob Allen Key compared to winter rainfall in South Florida (NOAA region #5) for the period 1880–1995. The rainfall record is a 7-point running mean. Note that during most dry periods, when Florida Bay salinity was high, *L. matagordensis* abundance is low; the opposite situation is seen during wet periods. See text.

There is also a large body of literature on 20th century trends in extreme weather events, including tropical cyclones and extra-tropical storms (see Nicholls *et al.*, 1996). Most studies, however, have been carried out on global or hemispheric scales and the impact of long-term climate trends on Florida is uncertain. One exception is the study of a 240-yr isotope record from a *Monastrea* coral from Biscayne Bay, Florida by Swart *et al.* (1996b). They discovered from oxygen isotopic patterns that the 20th century may have been significantly wetter than most of the 18th and 19th centuries. If such a trend were characteristic of the latter part of the 20th century in the nearby Florida Bay area, one would expect the net effect to be a long-term de-

crease in salinity, rather than increasing periods of hypersalinity.

At this time, the climatological and canal hypotheses seem to account for observed temporal trends in epiphytes and vegetation described above. Natural processes have certainly exerted strong influence on Florida Bay habitats over the past century and continue to do so. But the degree of impact may have been altered, perhaps even exacerbated in some areas, by anthropogenic diversion of freshwater inflow. The shift in Florida Bay benthos during the mid-century, the relationship between *Loxoconcha* and rainfall/salinity, and the large amplitude of post-1950 faunal events, all suggest that further investigation of the relationship between cli-

matological processes, such as ENSO and PNA, and the timing of Florida Bay ecosystem changes are warranted. Moreover, while climatological variability would have affected the entire Florida Bay ecosystem, information about the direct causes of seagrass die-offs, such as disease or light attenuation, need further study within the context of climate variability.

In regard to the topic of restoration of the "natural state" of Florida Bay seagrass and algae, our data support historical observations that central Florida Bay has experienced oscillations in the availability of seagrass and macro-benthic algal habitats that have been especially severe during the past 30 years. Generally,

seagrass and algal habitats in the studied part of Florida Bay have been much more abundant and/or dense during the last 50 years than during the first half of the century. Thus, how one defines the "natural state" of Florida Bay then depends on the period one selects. It is very likely that central and eastern Florida Bay had extensive seagrass and macro-benthic algal "meadows" during the mid-20th century and these meadows diminished during the 1970's and 1980's. However, seagrass and macro-benthic algal habitats were probably sparse in this region during the 19th and early 20th centuries, at least relative to the 1950s and 1960s.

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Appendix 1a.—Pass Key Ostracode census data.

Depth (cm)	Year	<i>P. setipunctata</i>	<i>Loxiconcha</i>	<i>Malzella</i>	<i>Xestoleberis</i>	Total Ostracodes
1	1997	0	13	52	16	118
3	1996	0	1	43	14	67
5	1995	0	0	34	7	55
9	1993	0	14	35	14	116
13	1991	0	15	35	15	124
17	1989	1	6	36	22	94
21	1987	0	8	50	15	112
25	1985	0	17	45	4	114
29	1983	0	21	33	7	94
33	1981	0	15	21	7	94
37	1979	0	3	26	17	86
41	1977	0	39	11	11	112
53	1971	0	48	16	8	121
69	1964	5	18	38	7	98
73	1962	0	47	20	14	108

Appendix 1b.—Ostracode species census data, Bob Allen Key core 6-A.

Depth (cm)	<i>Actino- cythereis</i> cf. <i>sub- quadrata</i>	<i>Acuticy- thereis</i> <i>laevis- sima</i>	<i>Aglaio- cypriis</i> sp.	<i>Cytherel- loidea</i>	<i>Cythero- morpha</i> <i>paracas- tanea</i>	<i>Cyther- ura</i> <i>elongata</i>	<i>Cyther- ura</i> <i>fiscina</i>	<i>Dolero- cypria</i> sp.	<i>Lepto- cythere</i> sp.	<i>Loxo- concha</i> <i>matagor- densis</i>	<i>Loxo- concha</i> spp.	<i>Malzella</i> <i>flori- dana</i>	<i>Neone- sidea</i> sp.
0		5		1						20		17	3
2		8	3	3	3		6			53	2	54	21
6		10	1	7			5			45	3	32	7
8				1			1			9	1	5	2
10		16		2						7		6	5
12	1	4		1						4		3	3
14							1			5	1	1	
16				1	1							2	1
18				1			2			3		7	1
20										1	1	4	
22				1			1			3	1		1
24		1		2			1			6	1	10	1
26		5		1			6			18	7	20	5
28			1	1						8		9	1
30		1		2	1		4			5	1	8	6
32			1	1			1			6	2	6	3
34				1						5	1	10	4
36		2		1						12	3	10	2
38		2	2	1			1			8		5	3
40		4		2			2			49	2	19	17
42		2		1	1		1			12	2	11	6
44		1		1						9	1	5	2
46	1	10		1			2			29	2	19	2
48	1	1			1		3			7	1	8	4
50	2	10		1		3	3	4		34		39	1
52	1	4		2	1	1	1			11	2	19	
54					1		2			14		13	1
56	2	2	1				2			16		7	5
58	3			1		1	1			10		6	3
60	1	2		1			1			9		7	
62		3	1	1		1				3		1	
64					2	1				15		7	1
66		2	4	1	1					11		11	1
68	1		3	2	2					11		5	
70			3							13		2	2
72					1					1		1	
74			1				1					1	2
76													
78										3			
80			1							1			
82										2		1	1
84													
86					1		1						
88			1		1		2			2		3	
90										1		1	
92							1						
94							1						
96													
98					2		1			3		7	
100												2	
102												1	
104												1	
106													
108										1		3	
110													
112												2	
114										1		1	
116													
118					1	1	1			3		1	

Appendix 1b.—Extended.

<i>Paracytheroma repexa</i>	<i>Paracytheroma stephensoni</i>	<i>Peratocytheridea bradii</i>	<i>Peratocytheridea setipunctata</i>	<i>Propontocypris</i>	<i>Proteonconcha</i>	<i>Puriana</i> spp.	<i>Radimella confregosa</i>	<i>Reticulocythereis floridana</i>	<i>Triangulocypris laeva</i>	<i>Xestoleberis</i> spp.	? <i>Microcythere</i>	Total Ostracodes
	1		7	1				2		10		67
9	4	2	14		3	1		3	13	67		269
12	1		33		3	1		4	5	28		197
5			4						1	1		30
3	3	2	43						4	1		92
4	1	10	52	1	2				9	4		99
2		6	46		1			8	3	3		77
1			11	2					1			20
3	2		6					1		5		31
2			8			1				2		19
3			5			1						22
		1	3			1		1	3	10		41
10			21			1		1	7	13		115
2	2		1						7	13		45
3			4	1	1			1	8	19		65
1			8					2	1	16		48
3			17						1	11		53
2	1		12						12	11		68
3	1							1	3	8		38
12	2	2	18						17	43		189
4	1		17					1	10	6		75
1			9						5	5		39
9	3	4	25		3	2		1	13	25		151
4	1	1	13			2		1	6	8		62
4	6	22	40		4	3	1	2	26	30		235
4	3	9	37		3	1			6	21		126
4		3	16		1	5			5	7		72
2		17	55		3	2			5	10		129
1		3	8			3	1		4	5		50
1			16			1				7		46
3		4	18						6	6	1	48
4			10			1			5	8		54
4			23						7	8		73
2	4		13	1		1			1	5	1	52
		2	13						1	2		38
	1		2									6
			13						4	4		26
			2						2			4
			2						2			7
2									5			9
1			6									11
			6									6
1		1	18						3	2		27
1		1	1						1	1		14
			8		2				1			13
			2			1			3			7
									2			3
	1		1									2
1		2	3						5			24
1		1	3					1				8
			1									2
			1						1			3
			2								1	3
2	1		3						3		1	14
											1	1
	1		3						1			7
			13						1			16
3			7									10
1	1		2		1				4			16

Appendix 1b.—Extended Continued.

<i>Paracy- theroma repexa</i>	<i>Paracy- theroma stephen- soni</i>	<i>Peratocy- theridea bradii</i>	<i>Peratocy- theridea setipunc- tata</i>	<i>Proponto- cypriis</i>	<i>Proteo- concha</i>	<i>Puriana spp.</i>	<i>Radimella confra- gosa</i>	<i>Reticulo- cythereis floridana</i>	<i>Triangulo- cypriis laeva</i>	<i>Xesto- leberis spp.</i>	<i>?Micro- cythere</i>	Total Ostracodes
			1								1	4
		1	1									3
			3									4
		2	6								1	10
		2										4
	2		6					1			2	13
	2		6			1			2		2	17
			2									6
			2		1	1			2		6	28
		2	2						2		3	13
2		1	12		2				2		1	32
2			18			1			3		3	50
1		1	7		1			1			2	17
			3								1	10
			6					1			3	13
			4						2		4	20
			8					1	1		3	25
2		2	18		2		1		7		8	78
	1		3				1		5		4	21

Appendix 1c.—Extended.

<i>Cythero-</i> <i>morpha</i> sp.	<i>Loxo-</i> <i>concha</i> <i>matagor-</i> <i>densis</i>	<i>Malzella</i> <i>floridana</i>	<i>Mega-</i> <i>cythere</i>	<i>Paracy-</i> <i>theridea</i>	<i>Perato-</i> <i>cythe-</i> <i>ridea</i> <i>setipunc-</i> <i>tata</i>	<i>Reticulo-</i> <i>cythereis</i> <i>floridana</i>	<i>Puriana</i> <i>convoluta</i>	<i>Thallosa-</i> <i>cypris?</i>	<i>Triangulo-</i> <i>cypris</i> sp.	<i>Xesto-</i> <i>leberis</i> spp.	Total Ostracodes
	15	31	1		16	36		1		17	148
	17	20		2	14	32				13	126
	12	11	3	1	15	30		6		9	109
	23	23	1		7	26		6		17	120
	19	21		1	8	9		2		22	106
	19	21	1	2	7	15		6	1	20	124
	11	21	1	1	9	10	1	4	3	18	100
	19	17	5	1	13	9		3	2	10	107
	15	20	2		12	14		6	1	11	109
	17	27	2	1	14	10	1	5	1	10	121
	19	28	4		10	1	1	6	6	8	107
	18	12			1	2		13		27	80
	14	30	5		6	9	2	4	2	17	109
	15	22	3		10	3	1	5		13	98
	30	28	8	1	3	5		12	1	26	134
1	19	20	2	4	5	8		17	3	28	131
1	19	27	1	1	1	1	3	15	9	25	128
	22	32	3	3	2	4	2	3	3	26	137
	18	28	2	3	5	4	2	5	8	20	123
1	20	37	2	4	2	3	10	6	11	28	145
2	23	26	1	6	4	3	4	4	6	23	135
3	26	28	1	3			2	7	14	41	148
3	17	33		6	1	2	8	7	5	45	148
2	15	39	2	5	1	3	5	8	8	37	150
3	24	20	1	3		3	4	12	5	26	122
3	25	15	1		1	3	2	3	4	21	116
	22	56		1	10	20	2		4	31	175
1	19	31	4	1	1	8	4		2	29	122
1	19	31	3		1	6	5	8	3	30	148
1	14	54	2	2	1	6	3	5	3	25	142
2	16	52	1		5	10	1	4	3	23	132
	10	42			5	5	2		2	22	103
	7	18	1	1	3	2		5		38	84
	14	44	2	1	6	1	2		7	19	106
	3	15				1	3	1		12	36
	7	69	2	1	10	16	4	1	6	5	129
	4	41	2		24	14	1		2	3	95
	5	93	2		10	11	2	1		18	154
	3	101	3		3	19	1			13	152
	5	81	2		8	19	2			12	135
	4	71	2		5	10				12	111
	3	92	3		5	7		2	1	12	132
	2	83		1	6	13				11	121
	4	90	2		9	12				6	133
	2	90			7	12				1	116
	3	88	1		16	16				7	137
		74			4	14				5	104
		81	1		4	13				10	117
	1	48	2		10	17	1			5	108
		18			3					3	28
	1	32			7	5				1	52
		56			12	19				3	110
		14			3	3				1	22
		3			3					1	8
											0
		17			5	2				3	79
	2	51	1		18	11	1				111
	2	46	1		19	10				3	127
											0

Appendix 1d.—Park Key core Ostracode census data.

Depth	Year	<i>P. setipunctata</i>	<i>Loxoconcha</i>	<i>Malzella</i>	<i>Xestoleberis</i>	Total ostracodes
1	1995	7	85	140	15	266
3	1992	18	84	111	26	299
5	1990	9	83	155	9	284
7	1987	16	70	143	14	291
9	1984	11	79	128	12	273
11	1982	14	72	127	17	284
13	1979	10	65	115	15	203
15	1977	13	76	140	13	324
17	1974	18	69	88	5	217
19	1972	14	29	51	4	141
21	1969	54	71	98	16	300
23	1967	33	66	98	11	290
25	1964	25	13	27	5	102
27	1961	4	9	6	2	33
29	1959	4	22	10	5	73
31	1956	45	29	53	15	238
33	1954	25	17	24	6	106
35	1951	8	50	151	14	286
37	1949	5	47	170	27	334
39	1946	0	17	47	14	113
41	1943	3	9	9	2	36
43	1941	20	82	129	30	371
45	1938	19	48	108	23	266
47	1936	30	72	110	11	334
49	1933	23	64	67	18	292
51	1931	35	50	56	12	225
53	1928	100	24	90	13	288
55	1925	31	45	42	15	193
57	1923	17	8	22	14	92
59	1920	54	38	54	12	227
61	1918	41	18	34	4	246
63	1915	1	0	0	1	5
65	1913	4	10	18	11	99
67	1910	2	0	0	1	7
69	1908	4	22	25	18	123
71	1905	0	63	89	33	255
73	1902	8	48	83	27	218
75	1900	1	7	11	4	31
77	1897	14	53	82	21	255
79	1895	20	19	48	13	140
81	1892	6	2	5	12	33
83	1890	8	37	61	83	301
85	1887	0	1	1	1	3

Appendix 1e.—Ostracode species census data, Russell Bank core 19-B.

Depth	Year	<i>Actino- cyther- eis</i> cf. <i>subqua- drata</i>	<i>Acuti- cyther- eis</i> <i>laevis- sima</i>	<i>Aglaio- cypris</i> sp.	<i>Aurila</i> <i>laevi- cula</i>	<i>Bytho- cy- therid</i>	<i>Cythe- rel- loidea</i>	<i>Cythero- morpha</i> <i>para- castanea</i>	<i>Cyther- ura</i> <i>elon- gata</i>	<i>Cyther- ura</i> <i>fiscina</i>	<i>Cyther- ura</i> <i>sablen- sis</i>	<i>Hemi- cyther- ura</i>	<i>Lepto- cythere</i> sp.	<i>Loxo- concha</i> <i>matagor- densis</i>	<i>Loxo- concha</i> spp.
0	1995						2	2	2	3				14	
2	1993						1	2	6	3				18	
4	1992						1	2	1	5	1			15	
6	1990	2	2				4	2		3				10	
8	1988	1					4		2	1	1		4	16	
10	1987		1				1		1	1	1		1	12	
12	1985	1					5		2	1				14	
14	1984			2			3	3	4	2			2	35	
16	1982			1			4	1	2	1				22	
18	1980	1		2					3	1				19	
20	1979							1		2				9	
22	1977		1	1			1	2	1		1			16	
24	1975	1	2	1			4	1						19	
26	1974	2	3	2			1	3		1	1		1	28	
28	1972	1	1				3	4		1			5	15	
30	1970		1	1			2	4	1	1			2	22	
32	1969		1				2	3					1	30	
34	1967	1	1	1			1	4	2	3			3	22	
36	1965		2				2	4	2	3				9	
38	1964		2				3	1	5	1				17	
40	1962	1	3				2	4	3	1				12	
42	1961	2	1				4	6	5	3				25	
44	1959	3					5	5	5					14	
46	1957						5	4	2					22	
48	1956	3					4	9	4					18	
50	1954	2					3	6	9					28	1
52	1952	1					4	1	3	1			3	24	
54	1951						2	2	2	1				35	
56	1949	1		1			1	4	4	1				30	
58	1947	1						7			1		3	29	
60	1946	3	2					4	1		2			15	
62	1944	3	5				7	5	3	2	1			27	
64	1943	6	2			1	2	9	1	1				25	
66	1941	2	1				1	9	4		4			14	
68	1939	3	2			1	2	10	4	2	2			18	
70	1938	3	1					3	4		1			12	
72	1936	2	7			1	1	2	6		1			13	1
74	1934	6	3				1		1	1	2			7	
76	1933	10	5			2	1	2						4	1
78	1931	9	5					1	1	2	1			7	1
80	1929	7	2		1		2			1	2		2	8	
82	1928	2	9	1			1	4	2					9	1
84	1926	8	6				1	5	3					3	
86	1924	4	7					7	2				1	12	
88	1923	3	4				1	2	2	1	1			5	
90	1921	5	1			1	1	3	3	1	1			5	
92	1920	2	5			1	1		2	3			1	8	
94	1918	2	8			1	1	3		1	2			6	1
96	1916	6				3	1	3	2	1				4	
98	1915	3				3	1	3			2			11	
100	1913	2		2		5	1	3			1			9	
102	1911	2	3	1		5		1			2			11	
104	1910	2	4	2		2	6				1			10	
106	1908	3	3	1				2	2		1			6	1
108	1906	3	7				1	8	5		1			13	
110	1905	2	1	1		1	2	4	2	2				9	
112	1903	1	4			3		4	4		1	1	2	5	
114	1902	5	3					1	1					4	

Appendix 1e.—Continued.

Depth	Year	<i>Mai- zella flori- dana</i>	<i>?Mi- cro- cythere</i>	<i>Neo- caud- ites triplis- triatius</i>	<i>Neone- sidea</i>	<i>Para- cyther- idea tschop- pi</i>	<i>Para- cyther- oma repexa</i>	<i>Para- cyther- oma steph- ensoni</i>	<i>Perato- cyther- idea bradyi</i>	<i>Perato- cyther- idea seti- punc- tata</i>	<i>Proteo- concha</i>	<i>Puri- ana spp.</i>	<i>Radi- mella con- fragosa</i>	<i>Reticu- locyth- flori- dana</i>	<i>Tri- angulo- cypris laeva</i>	<i>Xesto- leberis spp.</i>	Other	Total
0	1995	25			1						3	1			2	40		95
2	1993	32	1		2		3	1			1	4		1		23		98
4	1992	39					1	3				3				35		106
6	1990	36			2		1	1				1			1	39		104
8	1988	39			4		1	1			1	2				32		109
10	1987	37	1				3	1		2					1	41		104
12	1985	35	6		1			2			3				1	32		103
14	1984	17	3		4		1			1					1	36		114
16	1982	45	1		1		2			2	2	2		1	1	28		116
18	1980	39			1							1		1	1	41		110
20	1979	52	2		2	1	1	2		1		1				26		100
22	1977	46						3		2		3				27		104
24	1975	23	1		1	1		5	1	1	2	2		2	3	30		100
26	1974	21	3					4	1	2				2		28		103
28	1972	39					1	3	1			1		2	1	21		99
30	1970	35	3		3		3	7		6	4	2		2		15	1	115
32	1969	39			2			6	1	7	2	1			1	12		108
34	1967	36	2		4		1	4			1	2		1	1	16		106
36	1965	46	1	1	1			1			2	1			2	22		99
38	1964	57	4		3			5	1	4		1			1	17		122
40	1962	38	2		1		2	3	1	8		1		1	2	27		112
42	1961	16			5			5		5					1	36		114
44	1959	19	3		4		1	5	1	1					1	42		109
46	1957	16	1		2		2	9		2					4	36		105
48	1956	25	1		5		2	4		7	4	1			2	23		112
50	1954	11	1		2			6		2		2			1	47		121
52	1952	14	2		2			15		1					1	26		98
54	1951	13	8		4			9		3					2	32		113
56	1949	29	3				2	12		4		1			1	27		121
58	1947	11	6					10		5		2		1	7	14		97
60	1946	33	3		2			13		6	2	1		1	10	17		115
62	1944	23	1		2		2	14		7	1	3			5	36		147
64	1943	34			5	1	1	11		7	2	3		1	8	17		137
66	1941	31	3		2	1	4	8	1	6	2	7			4	16		120
68	1939	28	2			1	3	4		5	2	4		2	4	13		112
70	1938	46					2	2	3	9	4	11		4	4	4		113
72	1936	37	1		2		3	5	2	9	3	10		1	5	10		122
74	1934	42						2	5	15	2	8	1	3	5	5		109
76	1933	51	1			2	1	1	3	23	2	6		3	3	3		124
78	1931	42							1	23	3	8	1	3	6	9		123
80	1929	40	2	1			4	2	2	12	3	10		5	2	4		112
82	1928	44			1		3		2	13	3	6	1	3	4	9		118
84	1926	43					4		2	6	2	5			2	2		92
86	1924	43		1	1		3	2	1	15	4	3		4	5	9		124
88	1923	35					8		2	15	2	10	1	1	3	10		106
90	1921	32			1		5	1		19		3	1		5	8		96
92	1920	30	1		2	1	4			11	2	6		4	4	14	1	103
94	1918	47	1				5	3		6	6	3				9		105
96	1916	35			2		9	1		16	2	4	1	4	4	16		114
98	1915	45					5			15				2	2	7		99
100	1913	42			1		5			14		3		6	1	14		109
102	1911	42			1				3	17	2	6	1	2	1	10		110
104	1910	51			1	1	4	2	1	10	2	6		5	1	21		132
106	1908	42			1	1			1	10	5	4		3	1	14		103
108	1906	31					6	1	1	5	3	10		1	2	17		115
110	1905	31	2				4	2	3	14	1	6		1	3	9	2	102
112	1903	33			1		3		1	18	3	3		4	6	9	1	107
114	1902	28					3		1	21				1	1	4		73

Appendix 1e.—Continued.

Depth	Year	<i>Actino- cyther- eis</i> cf. <i>subqua- drata</i>	<i>Acuti- cyther- eis</i> <i>laevis- sima</i>	<i>Aglaio- cypris</i> sp.	<i>Aurila laevi- cula</i>	<i>Bytho- cy- therid</i>	<i>Cythe- rel- loidea</i>	<i>Cythero- morpha para- castanea</i>	<i>Cyther- ura elon- gata</i>	<i>Cyther- ura fiscina</i>	<i>Cyther- ura sablen- sis</i>	<i>Hemi- cyther- ura</i>	<i>Lepto- cythere sp.</i>	<i>Loxo- concha matagor- densis</i>	<i>Loxo- concha spp.</i>
116	1900	2				1	1	1							
118	1898	2	2			1	1	3	1		2			12	1
120	1897	3	1				2	1						3	
122	1895		4					3			1			6	
124	1893	4	6				1			1				7	
126	1892	2	2	1			1	3	1					1	1
128	1890	7	4				1		1		1			4	1
130	1888	3		1			2	1		1	3			5	
132	1887	3	3			1	2	3						1	
134	1885	1	2			1	1	2		1			1	4	
136	1883	1	6			1	6	2	1	2				9	1
138	1882	6				2	1	4	2				1	13	
140	1880	5	5			1			1	2				2	1
142	1879	2	14	1	1		2			2	1			13	

Appendix 1f.—Ostracode species census data, Taylor Core T-24.

Depth (cm)	<i>Acuti- cythereis laevis- sima</i>	<i>Candona</i>	<i>Cypretta</i>	<i>Cypris sp.</i>	<i>Cyprideis salebrosa</i>	<i>Cypri- dopsis okee- chobei</i>	<i>Cythero- morpha paracas- tanea</i>	<i>Cytherura sandbergi</i>	<i>Cytherura cf. reticu- lata</i>	<i>Dolero- cypria sp.</i>	<i>Hetero- cypria punctata</i>	<i>Lepto- cythere sp.</i>	<i>Limno- cythere floridana</i>
0	1			2	16	1	3	11		1			
2				1	14		2	17					
4			1		9	1		23		1			
6				3	11		2	12	1			1	
8		1		1	11	1	8	18	2			1	
10		1		2	22	1	2	12	1				3
12	2	2		5	27	1	4	18	1	1		1	1
14				2	15		1	8					
16				2	12	1		9	1				1
18				2	9	1		4	1				
20				1	9		1	3					1
22					11		1	3	1			2	2
24				1	10		1	2					
26				4	26			3					1
28				3	6	2		1					
30				1	15			4	2				1
32		1			11	2		7	2				1
34			1	1	15			3	1	1			1
36				3	11	1		3				1	1
38				1	12				2				
40				2	13	1		1					2
42				2	10	2	1	5					
44				2	14			2					1
46					8							1	1
48				1	5	1	1	1	2				
50				2	7		1	1					
52			1	1	9	3		6					
54				1	9	2		4				2	2
56				1	7	2		8	1				3
58				3	11	3		5				2	1

Appendix 1e.—Extended.

<i>Maizella</i> <i>flori-</i> <i>dana</i>	<i>?Mi-</i> <i>cro-</i> <i>cythere</i>	<i>Neo-</i> <i>caud-</i> <i>ites</i> <i>tripolis</i>	<i>Neone-</i> <i>tschop-</i> <i>sidea</i>	<i>Para-</i> <i>cyther-</i> <i>idea</i> <i>pi</i>	<i>Para-</i> <i>cyther-</i> <i>oma</i> <i>steph-</i> <i>ensoni</i>	<i>Perato-</i> <i>cyther-</i> <i>idea</i> <i>bradyi</i>	<i>Perato-</i> <i>cyther-</i> <i>idea</i> <i>punctata</i>	<i>Proteo-</i> <i>concha</i>	<i>Puriana</i> <i>spp.</i>	<i>Radi-</i> <i>mella</i> <i>con-</i> <i>fragosa</i>	<i>Reticu-</i> <i>locyth-</i> <i>ereis</i> <i>flori-</i> <i>dana</i>	<i>Triang-</i> <i>ulo-</i> <i>cypris</i> <i>laeva</i>	<i>Xesto-</i> <i>leberis</i> <i>spp.</i>	Other	Total
12			1		1	2	1		3		2	1	2		30
24	1		1		2	1	13	5	2		5	3	13	1	96
20					2		6	1	5		3	1	4	1	53
20	1		2	1	1		7	1			1	7	7	1	63
39			2		2		4		2			3	16		95
39	1		1		1		3	7	2	7	2	1	10		86
34	1		1		3		4	10	3	11	9	2	7		104
48	1		1		4	1	1	15	4	6	1	1	8		107
46	1				1			11	1	8	2		14		97
49				1	1			8	1	6	1		8		88
35	1			1	2		1	13	4		2	6	14		108
35					4		2	7	1	6	2	2	6		94
37			2		3		4	6	6	2		5	7		89
35			4		6		2	4	1		1	8	18		115

Appendix 1f.—Extended.

<i>Loxo-</i> <i>concha</i> <i>matagor-</i> <i>densis</i>	<i>Malzella</i> <i>floridana</i>	<i>Parapon-</i> <i>toparta</i> <i>sp.</i>	<i>Para-</i> <i>cythero-</i> <i>ma</i> <i>repexa</i>	<i>Para-</i> <i>cythero-</i> <i>ma</i> <i>stephen-</i> <i>soni</i>	<i>Peratocy-</i> <i>theridea</i> <i>seti-</i> <i>punctata</i>	<i>Perisso-</i> <i>cytheridea</i> <i>brachy-</i> <i>forma</i>	<i>Perisso-</i> <i>cytheridea</i> <i>cf.</i> <i>cribrosa</i>	<i>Reticulo-</i> <i>cythereis</i> <i>floridana</i>	<i>Thalasso-</i> <i>cypria</i>	<i>Xesto-</i> <i>leberis</i> <i>spp.</i>	Other	Total Ostracodes
19	48		2	1		28	4		1	10		148
18	48					38	5	2		7		152
24	50		2	1	5	47	3	1	1	9	3	181
24	42		3			50	7		2	7		165
27	59		3	1		68	7	2	3	13		226
23	75	1		1	3	74	8	2		5		236
24	103	2	3	1	1	135	10	3		13		358
16	41				1	54	16		1	4	1	160
10	65		1	1	1	71	4	1		6	2	188
10	21				1	44	10			1		104
11	31		1			53	8					119
10	43	3				73	5	1		3	1	159
4	28		2			43	2			2		95
5	13					45	11		1	1		110
5	21					59	4					101
9	21		2			42	7			3		107
5	20				2	54	1			2		108
5	21		1		2	37	6		3	1	1	100
10	23		1		2	33	8			3		100
5	20	3	1			54	2			3		103
14	24		1		3	32	3	1		1		98
11	22	1	1			39	3		1	4		102
9	31					33	5	1		5		103
12	31	2	2			36	2	2	2	5	1	105
17	27	4	4		1	35	2			5		106
6	38	3	3		1	32	3			5		102
11	40	1	1		1	29	3			5		111
12	31				2	36	6		1	2		110
6	19				1	45	2	2		3		100
7	19	2	2			51	3			2		111

Appendix 1g.—Whipray Key Ostracode census data.

Depth (cm)	Year	<i>P. seti-</i> <i>punctata</i>	<i>Loxo-</i> <i>concha</i>	<i>Malzella</i>	<i>Xesto-</i> <i>leberis</i> spp.	Total ostracode
1	1995	11	8	6	11	57
5	1985	9	8	24	37	107
9	1976	0	19	28	9	99
13	1967	2	10	31	23	95
17	1957	7	9	32	15	115
21	1948	6	10	27	14	109
25	1939	11	9	28	8	102
29	1930	29	9	22	5	101
33	1920	29	7	45	2	145
37	1911	27	5	32	3	100
41	1902	14	6	58	0	97
45	1892	10	20	32	8	98
49	1883	12	3	17	8	52
53	1874	43	2	23	0	81
57	1864	34	3	6	2	56
61	1855	40	3	13	2	85
65	1846	77	10	21	1	127
69	1837	61	2	43	1	146
73	1827	40	2	31	1	108
77	1818	12	17	49	4	125
79	1813	21	7	29	2	91

Appendix 2.—Ostracode species occurrence on Florida Bay seagrasses and marine algae.

Sample ID	ID number	Substrate	<i>Actino-cythereis</i>	<i>Aglaio-cypris</i> sp.	<i>Acuti-cythereis laevis-sima</i>	<i>Aurila laevicula</i>	Bairdiids	<i>Cytherura cybaea</i>	<i>Cytherura fiscina</i>	<i>Cytherura sandbergi</i>	<i>Cytheromorpha</i> sp.	<i>Cypri-deis</i>	<i>Cythere-reliids</i>	<i>Hemicytherura</i> sp.	<i>Lox-concha mata-gor-densis</i>	<i>Loxo-concha</i> sp.	<i>Mal-zella florida-dana</i>
FB1	1	G	1				2	4		6	3				52		23
FB1	4	G	4					1	2	3					21		92
FB1	5	G					2	3		5	1		2		29		33
FB11	1	G	1					2	1	2	1				17	1	51
FB11	2	A					1	3	1				1		18		7
FB11	3	G							2				1		1		24
FB11	5	G	1	2				3	2		10		2		21		38
FB12	1	A													1		
FB12	2	A				1							1		28	3	13
FB12	3	G	2						4		6	3	2		8	1	43
FB12	4	G						1							2		1
FB12	5	G						1	4		17		1		11		37
FB14	1	G		1			3					4	2		35		19
FB16	1	G													100	1	1
FB16	2	A					1								57		2
FB16	3	A		1											70		18
FB17	1	G		1			1						2		7		1
FB17	2	A		1			50	5	2				3	2	18		2
FB17	3	A		1			17						1		40		9
FB18	2	A				11	2						1	1	20		
FB20	1	G						2	1		3				15		7
FB20	2	G		1					1		5		1				16
FB20	3	A													2		1
FB20	4	A									1		1				1
FB20	5	A													5		2
FB21	1	G		2			2		1						42	2	7
FB21	shell	S	2		2				7			4			22	12	8
FB22	1	G	2	1			1	1					1		26	2	18
FB23	1	G												2	1		
FB26	1	G		5				1					1		52	1	2
FB26	2	G													9		
FB4	4	G	1		1			1	2		3		2		16		9
FB5	1	A	1						1		2				9		8
FB5	2	A	1	1			3		3		2		4		24		42
FB5	3	A													4		
FB5	5	A	1					6	2		1		1		29		19
FB6	shell	S	3		1		4					29			4	1	10
FB8	1	G						1			1				18	3	68
Total for 36 veg samples			15	17	1	12	85	35	29	16	56	7	30	5	808	14	614
% for 36 veg samples			0.564	0.64	0.038	0.451	3.198	1.317	1.091	0.602	2.107	0.263	1.129	0.188	30.4	0.527	23.1
Total for 2 sand samples			5	0	3	0	4	0	7	0	0	33	0	0	26	13	18
% for 2 sand samples			2.092	0	1.255	0	1.674	0	2.929	0	0	13.81	0	0	10.88	5.439	7.531
Total for 15 algal samples			3	4	0	12	74	14	9	0	6	0	13	3	325	3	124
% algal samples			0.281	0.375	0	1.126	6.942	1.313	0.844	0	0.563	0	1.22	0.281	30.49	0.281	11.63
Total for 21 Grass samples			12	13	1	0	11	21	20	16	50	7	17	2	483	11	490
% Grass samples			0.754	0.817	0.063	0	0.691	1.319	1.256	1.005	3.141	0.44	1.068	0.126	30.34	0.691	30.78

* *Perissocytheridea troglodyta* and *P. rugata*.** Some *Triangulocypris*, *Thalassocypris*, indeterminate taxa.# Includes *Puriana*, *Leptocythere*, *Caudites*.

Appendix 2.—Extended.

<i>Megacythere johnsoni</i>	<i>Paracytheroma stephensoni</i>	<i>Perato- cytheridea seti- punc- tata</i>	<i>Perato- cytheridea bradyi</i>	<i>Peris- socytheride*</i>	<i>Reticu- locytheris</i>	<i>Thal- asso. & Tri- ang.**</i>	<i>Xesto- leberis spp.</i>	Other #	Total	Vegetation
2	3			2		1	19		118	<i>Laurencia, Thalassia</i>
	1	4		9	2		11	1	151	<i>Thalassia, Halodule, Laurencia</i>
1				1	1	1	13		92	<i>Thalassia, Polysiphonia, Laurencia</i>
1	1	15			1	1	11	6	112	<i>Thalassia, Polysiphonia</i>
							32	2	65	<i>Chondria, Thalassia</i>
								3	31	<i>Halodule, Thalassia</i>
	1	12			2			4	98	<i>Thalassia, Chondria, Polysiphonia</i>
							1		2	<i>Sargassum</i>
				2			34		82	<i>Chondria, Polysiphonia, Laurencia, Thalassia</i>
2		9		4			13		97	<i>Thalassia</i>
								1	5	<i>Halodule</i>
1	11	25	3		1		1		113	<i>Thalassia</i>
	1	10			2	1	62		140	<i>Ruppia, Halodule, Thalassia, Laurencia</i>
2							9	2	115	<i>Thalassia, Laurencia, Batophora</i>
		1					58		118	<i>Laurencia, Batophora, Thalassia</i>
		2				3	35		128	<i>Polysiphonia, Batophora, Thalassia, Halodule</i>
							7	1	22	<i>Thalassia, Chondria</i>
						4	28	2	117	<i>Chondria, Thalassia</i>
1		2				4	40			<i>Chondria, Polysiphonia, Thalassia, Halodule,</i>
									115	<i>Laurencia</i>
2		1				1	16	2	57	<i>Syringodium</i>
1					1		3		33	<i>Thalassia, Polysiphonia</i>
	1						2	1	28	<i>Halodule</i>
									3	<i>Chondria, Polysiphonia, Thalassia</i>
							2	1	6	<i>Chondria, Batophora, Thalassia</i>
									7	<i>Polysiphonia</i>
					1	2	15		74	<i>Thalassia, Halodule, Laurencia</i>
4		47			1		2		111	shell
1		1			1		25		80	<i>Thalassia, Laurencia</i>
							1	1	5	<i>Syringodium, Thalassia, Chondria,</i>
										feathery algae
1						8	22		94	<i>Halodule, tulip-like algae, Thalassia,</i>
		1								<i>Laurencia, Chondria</i>
		1					5		15	<i>Halodule, Thalassia</i>
		2					10	1	48	<i>Thalassia, Sargassum, Polysiphonia</i>
		2			1		78	2	104	<i>Siphonia, Batophora, Chondria (2 species),</i>
										<i>Thalassia, Laurencia, Halodule</i>
3		3	3			2	34	3	128	<i>Laurencia, Acetabularia, Enteromorpha,</i>
							4		8	<i>Halodule, Batophora</i>
										<i>Laurencia, Chondria, filamentous</i>
										green algae
2	2		2				60	1	126	<i>Laurencia, green mossy filamentous algae,</i>
										<i>Batophora, Chondria, Halodule, Thalassia</i>
		69	1		2		4		128	shell
1				9			17	3	121	<i>Thalassia</i>
21	21	91	8	27	13	28	668	37	2658	
0.79	0.79	3.424	0.301	1.016	0.489	1.053	25.13	1.392		
4	0	116	1	0	3	0	6	0	239	
1.674	0	48.54	0.418	0	1.255	0	2.51	0		
8	2	9	5	2	1	14	422	13	1066	
0.75	0.188	0.844	0.469	0.188	0.094	1.313	39.59	1.22	100	
13	19	82	3	25	12	14	246	24	1592	
0.817	1.193	5.151	0.188	1.57	0.754	0.879	15.45	1.508	100	

Appendix 3—Modern ostracode data for 1995.

Slide	Location	<i>Actino- cythe- reis sub- quad- rata</i>	<i>Acuti- laevis- sima</i>	<i>Aglaie- cypri- s</i>	<i>Caud- ites</i>	<i>Proteo- concha tuber- culata</i>	<i>Cypri- deis</i>	<i>Cypri- s</i>	<i>Cytherel- loidea</i>	<i>Cy- thero- mor- pha para- cas- tanea</i>	<i>Cy- ther- ura elon- gata</i>	<i>Cyther- ura</i> sp.	<i>Cy- ther- ura fiscina</i>	<i>Dolero- cypria sp.</i>
95GLW16	Bob Allen Keys					1			1	7		1		
95GLW17	Bob Allen Keys	3		2										
95GLW18A	Shell Creek—mouth								1		3		9	
95GLW18B	Shell Creek—mouth						4	1			2	2	3	2
95GLW19A	Trout Creek—mouth						9				0		7	1
95GLW19B	Trout Creek—mouth									2		5		4
95GLW20A	Duck Key	1			1		6			1	5			
95GLW20B	Duck Key	1	3	2		1			4	1	7	1		
95GLW21	Nest Key	5	1	2		3			11	9	3			1
95GLW22A	Porjoe Key	1	1			1			1		3		1	
95GLW22B	Porjoe Key			1					3	2	5		3	
95GLW22C	Porjoe Key	1							4	8	4	1	4	
95GLW22D	Porjoe Key	1							4	2	7			2
95GLW23	Butternut Key	2	1			11	6				1	1		0
	Bob Allen Keys	0.95	0	0	0	0.95	0	0	0.95	0	0	0.95	0	0
	Bob Allen Keys	3.16	0	2.11	0	0	0	0	0	7.37	0	0	0	0
	Shell Creek—mouth	0	0	0	0	0	0	0	1.01	0	3.03	0	9.09	0
	Shell Creek—mouth	0	0	0	0	0	4.3	1.08	0	0	2.15	2.15	3.23	2.15
	Trout Creek—mouth	0	0	0	0	0	9	0	0	4	0	0	7	1
	Trout Creek—mouth	0	0	0	0	0	0	0	0	6.67	0	16.7	0	13.3
	Duck Key	1	0	0	1	0	6	0	0	1	5	0	0	0
	Duck Key	1.03	3.09	2.06	0	1.03	0	0	4.12	1.03	7.22	1.03	0	0
	Nest Key	4.5	0.9	1.8	0	2.7	0	0	9.91	8.11	2.7	0	0	0.9
	Porjoe Key	1.22	1.22	0	0	1.22	0	0	1.22	0	3.66	0	1.22	0
	Porjoe Key	0	0	0.96	0	0	0	0	2.88	1.92	4.81	0	2.88	0
	Porjoe Key	0.89	0	0	0	0	0	0	3.57	7.14	3.57	0.89	3.57	0
	Porjoe Key	1.01	0	0	0	0	0	0	4.04	2.02	7.07	0	0	2.02
	Butternut Key	3.28	1.64	0	0	18	9.84	0	0	0	1.64	1.64	0	0
	Bottle Key	1.22	0.49	0.5	0.07	1.71	2.08	0.08	1.98	2.8	2.92	1.67	1.93	1.39

Appendix 3—Extended.

<i>Limno- cythere flori- dana</i>	<i>Loxo- concha mata- gor- densis</i>	<i>Mal- zella flori- dana</i>	<i>Neo- nesidea sp.</i>	<i>Para- cy- thero- ma repexa</i>	<i>Para- cy- thero- ma steno- phen- soni</i>	<i>Para- cy- thero- ma repexa</i>	<i>Perato- cythe- ridea bradii</i>	<i>Perato- cythe- ridea seti- punc- tata</i>	<i>Perisso- cythe- ridea</i>	<i>Perisso- cythe- ridea brachy- forma</i>	<i>Peris- so- cythe- ridea cf. cri- brosa</i>	<i>Puri- ana</i>	<i>Reti- cula flori- dana</i>	<i>Thal. vavrai</i>	<i>Trian- gulo- cypis laeva</i>	<i>Xesto- leberis spp.</i>	Total
	13	27	6	1	2	1						1		4		46	105
	11	32		2				3		1		3	6	8		17	95
	12	49			1					2	3			4		15	99
	14	44		1						5	3					12	93
1	8	28		1						25	4			5		7	100
	18												1			30	
	8	30	3		2			2	30					1		10	100
	21	26	2		1	4	4				5		1	1		12	97
	22	20	3	2	5								1	4		19	111
	36	16	1					2				2		1		16	82
	22	32	4		1			3					1		1	26	104
	24	19	1	3	5		1	6						3		18	112
	25	13		2	1			4				1	3			34	99
	2	12		2				4				1		1		17	61
0	12.4	25.7	5.71	0.95	1.9	0.95	0	0	0	0	0	0.95	0	3.81	0	43.8	100
0	11.6	33.7	0	2.11	0	0	0	3.16	0	1.05	0	3.16	6.32	8.42	0	17.9	100
0	12.1	49.5	0	0	1.01	0	0	0	0	2.02	3.03	0	0	4.04	0	15.2	100
0	15.1	47.3	0	1.08	0	0	0	0	0	5.38	3.23	0	0	0	0	12.9	100
1	8	28	0	1	0	0	0	0	0	25	4	0	0	5	0	76	100
0	60	0	0	0	0	0	0	0	0	0	0	0	3.33	0	0	0	100
0	8	30	3	0	2	0	0	2	30	0	0	0	0	1	0	10	100
0	21.6	26.8	2.06	0	1.03	4.12	4.12	0	0	0	5.15	0	1.03	1.03	0	12.4	100
0	19.8	18	2.7	1.8	4.5	0	0	0	0	0	0	0	0.9	3.6	0	17.1	100
0	43.9	19.5	1.22	0	0	0	0	2.44	0	0	0	2.44	0	1.22	0	19.5	100
0	21.2	30.8	3.85	0	0.96	0	0	2.88	0	0	0	0	0.96	0	0.96	25	100
0	21.4	25.9	0.89	2.68	4.46	0	0.89	5.36	0	0	0	0	0	2.68	0	16.1	100
0	25.3	13.1	0	2.02	1.01	0	0	4.04	0	0	0	1.01	3.03	0	0	34.3	100
0	3.28	19.7	0	3.28	0	0	0	6.56	0	0	0	1.64	0	1.64	0	27.9	100
0.07	20.3	26.3	1.39	1.07	1.21	0.36	0.36	1.89	2.14	2.39	1.1	0.66	1.11	2.32	0.07	18.5	

CHAPTER 10

MOLLUSCAN FAUNAL DISTRIBUTION IN FLORIDA BAY, PAST AND PRESENT: AN INTEGRATION OF DOWN-CORE AND MODERN DATA

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ABSTRACT

Statistical comparison of modern molluscan fauna to down-core molluscan assemblages in four cores elucidates changes in the Florida Bay ecosystem during the past 100 to 200 years. Fluctuations within molluscan faunal dominance and diversity patterns suggest a response to changing environmental conditions. Faunal dominance patterns indicate an increase in salinity in the northern transitional zone, and possibly the eastern portion of Florida Bay. Distinctive faunal shifts recorded at Russell Bank occur approximately between 1913 and 1933 and at Bob Allen mudbank between approximately 1900 and 1910. The period from approximately 1930 to 1980 within these cores shows rapid and dramatic fluctuations in species dominance and faunal richness. Beginning around 1980, the mussel *Brachidontes exustus*, which can tolerate diminished water quality and a wide range of salinities, increases in percent abundance in the upper portion of all four cores and becomes the dominant species at Russell Bank and Bob Allen Mudbank.

While these fluctuations within assemblages are distinctive, they are not so profound that they represent a major shift in estuarine zonations within northern, eastern, and central Florida Bay during the past 100 to 200 years. The majority of the molluscan fauna that are present at the core sites today are generally present throughout the period of deposition. Fluctuations in the molluscan faunal record down-core primarily express changes in dominance and diversity within assemblages and do not reflect substantial changes in overall assemblages. It is these fluctuations in dominance and the appearance or disappearance of critical indicator species that are indicative of salinity changes.

Understanding the dynamics of an ecosystem and the natural range of variation in the system over an extended period of time is a critical component of effective restoration. Analysis of the modern environment provides a means to interpret biological data preserved in cores, and to determine the physical and chemical variations in the environment indicated by the biota. Knowledge of the past provides the best insight to predicting the impact of future change on the environment.

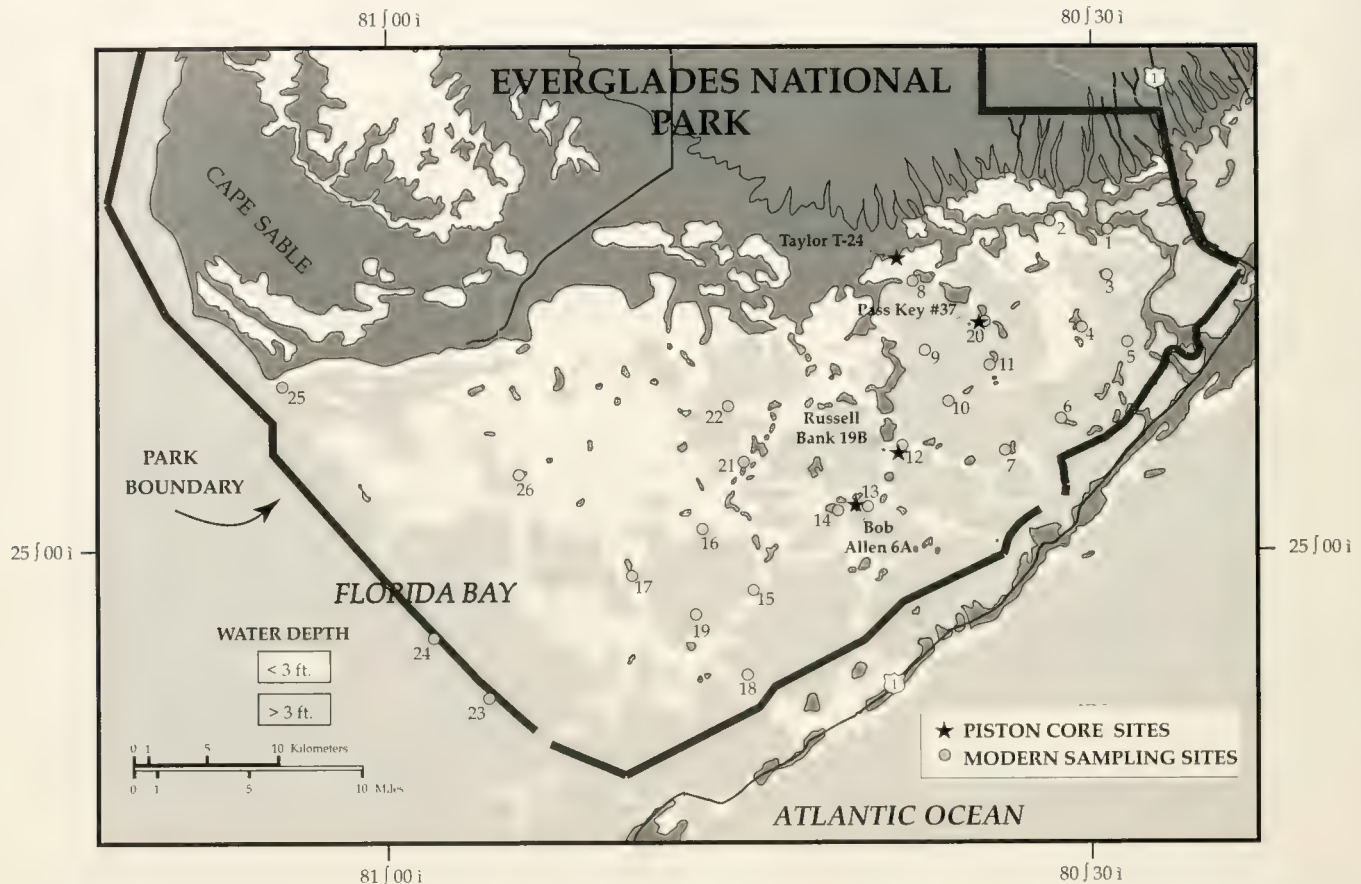
INTRODUCTION

Molluscs are an abundant and diverse component of the shallow coastal ecosystems of Florida. Two hundred and twenty-one families, 646 genera, and 1407 species of molluscs have been documented from the shallow marine environments of the state (Camp, Lyons, and Perkins, 1998). In Florida Bay alone, 235 species of molluscs were recorded by Lyons (1999) over the course of a three-year sampling period (1994–1996). This diversity can be attributed in part to southern Florida's position at the junction of two molluscan faunal provinces: the Caribbean and the Carolinian.

Molluscs are an integral part of the Florida Bay ecosystem. Different groups of molluscs are components of the micro-, meio-, and macro-fauna of the bay and as some species pass through their life stages they move from the plankton to the benthos. In addition, molluscs employ a number of feeding strategies, including filter feeding, grazing, scavenging, and carnivory. Consequently, molluscs occupy a number of trophic levels within the ecosystem and they fill many important niches as both predators and prey.

Analyzing historical patterns of change in molluscan

assemblages is a very powerful tool in reconstructing the history of an ecosystem. Estuarine molluscs tolerate a wide range of fluctuating environmental conditions, yet on a scale of seasons, their populations will migrate to more ideal conditions (Dame, 1996). Lyons (1996, 1998) has demonstrated molluscan migration within Florida Bay in response to seasonal and annual variations in salinity. Individual molluscs, however, are relatively limited in their movement in post larval stages, and typically provide information about a specific site for the duration of their lifetime. In addition, most molluscs are hard-shelled, and therefore well preserved in cores. Turney and Perkins (1972) related the distribution of molluscan death assemblages to environmental influences. On the basis of these previous studies, and given the ecological preferences of molluscs, we believe changes in molluscan assemblages identify significant perturbations of an environment and filter out "noise" caused by day to day or short-term fluctuations, such as those caused by tropical storms. By understanding the factors controlling modern distributions of molluscs, we can interpret patterns of change in the past, and in turn, predict future responses to human-induced or natural environmental change.



Text-figure 1.—Map of Florida Bay showing location of 26 monitoring sites and four cores. Boundary of Everglades National Park is shown by bold dashed line. Table 1 gives latitude and longitude.

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METHODS OF INVESTIGATION

FIELD METHODS

Twenty-six sites throughout Florida Bay (Text-fig. 1, Table 1), visited biannually between February 1995 and July 1999, constitute the source of modern observations. Biannual observation of sites always occurred between February 12–23 and July 6–13 for seasonal consistency. Sites 1–14, under regular observation

Table 1.—Location of 26 modern sampling sites and 4 cores shown on Figure 1.

Site Number	Site Name	Latitude	Longitude	
1	Shell creek mouth	N 25.20684	W 80.48701	
2	Trout Creek water monitoring station	N 25.21226	W 80.53345	
3	Duck Key water monitoring station	N 25.18012	W 80.48916	
4	Northern Nest Key	N 25.13104	W 80.50458	
5	Porjoe Key S mud bank	N 25.14121	W 80.47267	
6	Butternut Key water monitoring station	N 25.08677	W 80.51915	
7	Bottle Key SE mud bank	N 25.06092	W 80.55918	
8	Little Madeira Bay mouth	N 25.17580	W 80.63166	
9	Mid basin S of Little Madeira Bay	N 25.13433	W 80.62146	
10	Mid basin (between Park & Russell Key)	N 25.08494	W 80.58954	
11	Park Key SW bank	N 25.10628	W 80.56254	
12	Russell Key SE bank	N 25.07168	W 80.63814	
13	Bob Allen Keys mud bank	N 25.01892	W 80.66540	
14	Bob Allen Key water monitoring station	N 25.02647	W 80.68115	
15	Gopher Pass	N 24.98098	W 80.73686	
16	Mud bank SE of Sid Key & SW of Corinne	N 25.01227	W 80.76410	
17	Little Rabbit Key water monitoring station	N 24.98144	W 80.82515	
18	Peterson Key bank water monitoring station	N 24.91783	W 80.74662	
19	Mid basin N of Barnes Key	N 24.95348	W 80.78270	
20	Pass Key S mud bank	N 25.15314	W 80.57711	
21	Buttonwood Keys water monitoring station	N 25.07101	W 80.73588	
22	Whipray basin mud bank	N 25.08853	W 80.74182	
23	Sprigger Bank	N 24.91321	W 80.93768	
24	Schooner Bank	N 24.95971	W 80.97596	
25	Cape Sable	N 25.11344	W 81.07898	
26	Johnson Key water monitoring station	N 25.05240	W 80.90391	
Core Number				Date Collected
T24	Taylor Creek at mouth of Little Madeira Bay	N 25.2000	W 80.6417	
PK37	Pass Key - mud bank to south of Key	N 25.1478	W 80.5745	5/26/96
RB19B	Russell Bank to south of Russell Key	N 25.0639	W 80.6248	2/24/95
BA6A	Bob Allen mudbank, south east of Bob Allen Keys	N 25.0232	W 80.6568	5/26/94

since February 1995, have been visited consistently twice a year. Sites 15–26, added to the observations after February 1995, were typically less accessible in the ‘wet’ season (May–October) and as a result underwent more regular observation during ‘dry’ seasons (November–April) and less consistent observation during ‘wet’ seasons. Observations were obtained by wading or snorkeling at each site and recording the substrate, fauna and flora present (living and dead), and microhabitats. Observation procedures did not include digging within the sediment for infaunal organisms or a systematic search of the site, but represent a careful examination of the area. One hundred and seventy-five detailed site observations from February 1996 to July 1999 are analyzed statistically in this paper.

Each observation was coupled with a characterization of the water at the site and a sampling of the sediment. Water was characterized by salinity, temperature, depth, and clarity. Salinity values were calculated using a Hydrolab Surveyor 4, YSI Model 30/10 FT, or a refractometer. Temperature values were

obtained using a Hydrolab Surveyor 4 or YSI Model 30/10 FT.

In February and July 1998, seventeen sub-aquatic vegetation samples (macro-benthic algae and seagrass) were collected at sites 8, 12, 13, and 20. Sub-aquatic vegetation was sampled randomly, to characterize the types of flora present, and the associated epifaunal organisms. Sub-aquatic vegetation was collected without the roots or holdfasts (where present) to reduce the chance of contamination by infaunal organisms. Vegetation samples were collected with a small amount of concomitant water in an attempt to delay the effects of biodegradation before laboratory examination of the samples.

Sediment samples were collected using a 1.5 inch diameter PVC tube (push core). Push cores were pressed into the substrate, and a vacuum was maintained to extract the sediment. Push core tubes were cut at the water-substrate interface and sealed to prevent disruption of sediment during transport to the laboratory. The twenty-eight push cores described in this study were taken from four sites in northern and east-

ern Florida Bay (Text-fig. 1) biannually between February 1995 and July 1998 (collection at site 20 began February 1997), and represent a subset of the total number of push cores obtained. Push core samples were chosen for this study based upon proximity of modern sampling sites to the location of the four piston cores.

The four short piston cores (<2 m) examined were taken from Florida Bay localities (Text-fig. 1) between February 1994 and March 1996 by researchers from the U. S. Geological Survey (St. Petersburg, Florida), in cooperation with South Florida Water Management District, Everglades National Park, and National Oceanic and Atmospheric Administration (NOAA). Modern sites 12, 13, and 20 occur at the same location as piston cores RB19B, BA6A, and PK37, respectively. Site 8, located at the mouth of Little Madeira Bay, is the closest modern observation site to the site of piston core T-24, located at the mouth of Taylor Creek in Little Madeira Bay.

LABORATORY METHODS

Vegetation samples were characterized by type of sub-aquatic vegetation present and condition of the vegetation. All vegetation samples were then carefully examined for extant epifaunal organisms before processing. Samples were vigorously scrubbed to remove epifaunal organisms, washed through 850 μm and 63 μm sieves, and dried at 50°C. Dry vegetation material from each sample was weighed, re-hydrated, and washed through 850 μm and 63 μm sieves a second time to help remove any remaining epifaunal organisms.

All push cores were cut to 10 cm below the water-substrate interface, and this upper 10 cm of sediment was retained for processing. Twenty-eight push core samples were analyzed for faunal content. Piston cores collected for historical reconstruction were x-rayed and visually examined for signs of sediment disruption, including bioturbation. Samples from the piston cores were submitted for ^{210}Pb analysis (see Holmes, *et al.*, 2001, for method; Wingard *et al.*, 1995, and Brewster-Wingard *et al.*, 1997 for ^{210}Pb results on cores discussed here). All four piston cores were sampled at 2-cm intervals. All push core and piston core samples were washed through 850 μm and 63 μm sieves to remove carbonate mud. Samples were dried at 50°C.

All recognizable molluscs and molluscan fragments were picked from the 850 μm -size fraction from each vegetation, push core, and piston core sample. Picked specimens were sorted, identified, and characterized by condition of the shell material present. Specimens were characterized by stage (adult or juvenile) as well

as pristine (intact and retaining original shell material), whole (intact but lacking original shell material or color), broken (retaining original shell material and more than 50% of shell), worn, or fragmented (retaining less than 50% of the shell but still recognizable at the generic level).

Age models for the piston cores 6A and 19B are based on ^{210}Pb analysis of the <63 μm -size fraction of the samples. For details of the method, see Holmes, *et al.* (this volume).

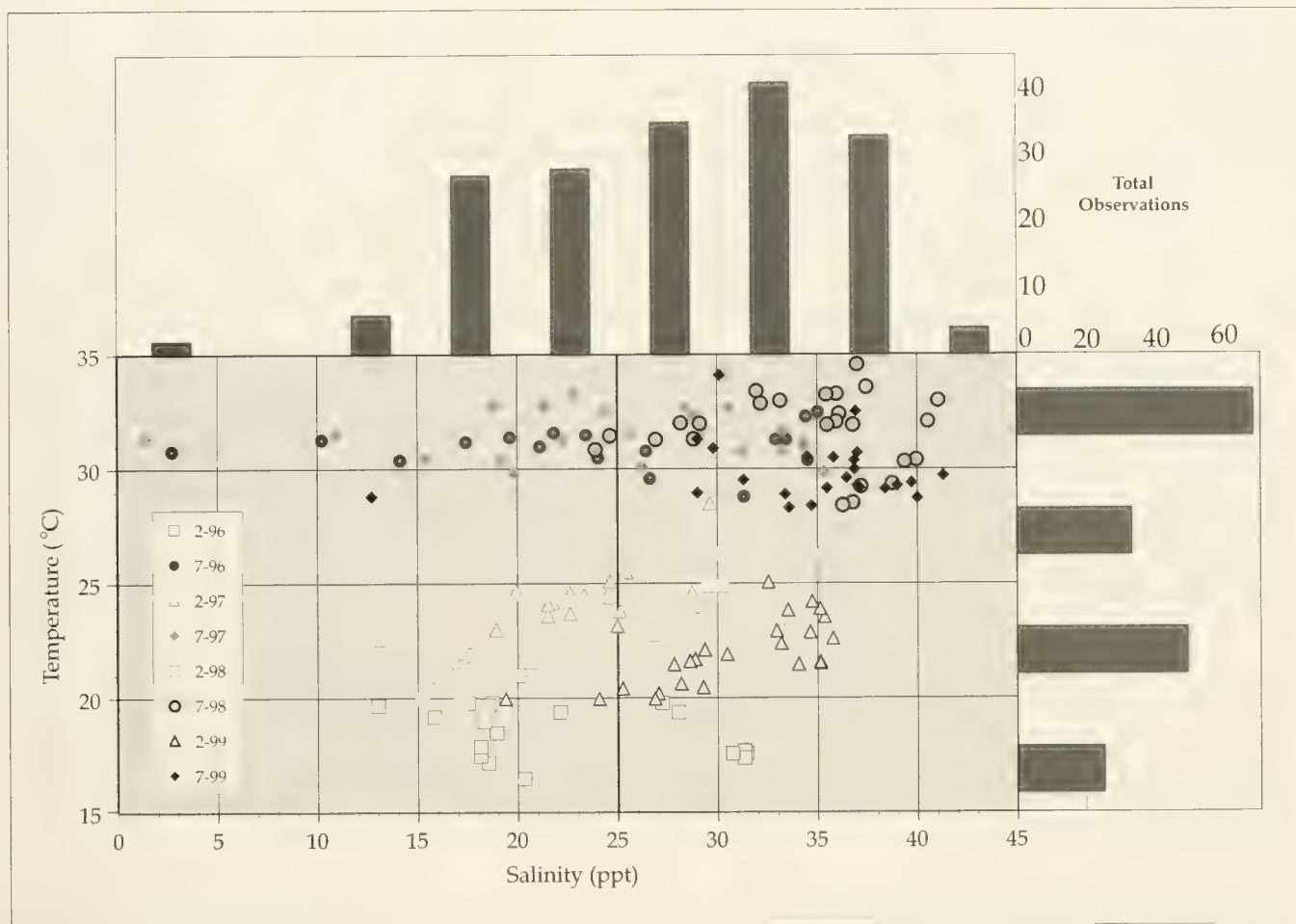
ANALYTICAL METHODS

Univariate and bivariate statistical analyses, including minimum, maximum, mean, median, and standard deviation, were conducted on environmental data (salinity and temperature), and individual species distributions using Microsoft Excel 97. For site observations, the presence-absence data were simplified for statistical analysis by deleting samples with no molluscs present and removing faunal groups that occur less than two times throughout the dataset. Observation data were translated into a presence-absence data matrix.¹ For the piston core, push-core and vegetation data, absolute species abundances were standardized by calculating percent relative abundance of the total molluscan component of the sample. Worn and fragmented molluscan specimens were removed from the analysis of vegetation samples, and from one run of push core samples, in order to isolate extant material from older material.

All multivariate analyses were done using MVSP (Kovach Computing Services, MVSP Plus, version 3.1) following the methods described by Kovach (1989, 1995). A cluster analysis of the presence-absence data was conducted using unweighted paired group method, average-linkage (UPGMA), with Sorenson's Coefficient distance measurement, dual clustering procedure, and random input order. Cluster analyses of percent abundance data were conducted with log-ratio transformed and centered data, then clustered using UPGMA, with cosine theta distance measurement, dual clustering procedure, and random input order. Each cluster analysis was run several times using random input order to determine robustness of clusters.

Constancy and fidelity measures were calculated for each cluster in both the presence-absence data analysis and the percent abundance data analysis. Method was adapted from Hazel (1977). Constancy is a measure of how frequently a species occurs within a given cluster, expressed as a percentage. The formula is

¹ The full data matrix can be found at <http://flaecoehist/database/Reference/synthesis>.



Text-figure 2.—Plot of temperature (°C) versus salinity (ppt) recorded at sites from February 1996 through July 1999. Histogram on x axis shows frequency of observations in 5 ppt increments. Histogram on y axis shows frequency of observations in 5°C increments. Bimodal nature of temperature readings reflects seasonality.

$$\text{Constancy} = (\text{Occurrence} \cdot 100)$$

$$\div \text{Total number of samples in cluster.}$$

A species with 100% constancy is present in every sample in a given cluster. Fidelity is a measure of how unique a species is to a given cluster (expressed as a percentage). The formula is

$$\text{Fidelity} = [(\text{Constancy in Cluster X})$$

$$\div (\sum \text{constancy values for all clusters})] \cdot 100.$$

Thus, it is possible for a species to have a high constancy value, if it is present in most samples in a cluster, but a low fidelity value if it also is commonly present in other clusters. Conversely, a species can be very rare and have a low constancy for a cluster, but a high fidelity because it occurs only in that cluster. A species with 100% fidelity is unique to that cluster.

Several measures of diversity were calculated on all piston core samples: 1) total number of individual molluscan specimens; 2) faunal richness; 3) evenness; and 4) Shannon's diversity index. Faunal richness in this study is a measure of the number of faunal groups present in a given sample (in the case of the presence-absence data observed at a given site). In some cases, the fauna are grouped into genera and occasionally broader categories (*e.g.*, marginellids), so this is not "species" richness in the usual sense. Evenness and Shannon's diversity index were calculated using MVSP. Evenness is a measure of how evenly dispersed the total number of individuals are among the faunal categories; the higher the value, the more evenly dispersed the individuals are. Shannon's diversity index (Shannon and Weaver, 1949; Ludwig and Reynolds, 1988) is a measure of the degree of uncertainty that a randomly selected individual will belong to a certain species. The formula is as follows:

Table 2.—Univariate statistics for temperature (degrees C) at each site.

Site	2-96	7-96	2-97	7-97	2-98	7-98	2-99	7-99	All years (February and July)				
									Mini- mum	Maxi- mum	Mean	Median	Standard deviation
1	19.00	30.40	23.00	30.50	21.00	31.30	20.62	29.16	19.00	31.30	25.62	26.08	5.19
2	19.70	30.80	23.70	31.40	22.00	31.47	20.41	28.80	19.70	31.47	26.04	26.25	5.10
3	17.20	31.40	23.80	32.80	21.40	32.00	20.45	29.18	17.20	32.80	26.03	26.49	6.04
4	19.80	31.20	24.60	32.70	21.60	32.88	21.46	29.61	19.80	32.88	26.73	27.11	5.46
5	16.50	31.60	25.50	32.90	21.90	33.42	22.09	30.37	16.50	33.42	26.79	27.94	6.22
6	19.70	29.60	24.40	32.40	21.00	33.29	21.68	30.49	19.70	33.29	26.57	27.00	5.48
7	19.40	30.80	25.10	32.70	20.70	33.59	21.89	32.52	19.40	33.59	27.09	27.95	5.95
8	19.20	31.30	24.70	31.60	20.00	30.86	19.96	29.52	19.20	31.60	25.89	27.11	5.55
9	17.90	31.00	24.10	30.40	19.40	31.32	19.96	28.31	17.90	31.32	25.30	26.21	5.65
10	17.50	31.40	24.20	31.30	18.40	31.94	19.96	28.39	17.50	31.94	25.39	26.30	6.15
11	19.80	30.50	23.60	33.30	19.40	32.99	20.19	30.53	19.40	33.30	26.29	27.05	6.14
12	18.50	31.50	24.50	30.10	21.60	34.58	21.60	28.95	18.50	34.58	26.42	26.73	5.67
13	19.80	31.30	24.60	30.80	22.20	32.10	22.37	30.90	19.80	32.10	26.76	27.70	5.01
14	19.40	31.30	26.00	31.70	23.80	33.01	22.92	34.10	19.40	34.10	27.78	28.65	5.45
15	17.40	28.80		31.70		28.54	22.86	28.73	17.40	31.70	26.34	28.64	5.24
16	17.60	30.40	28.50	31.70	26.30	29.38	23.54	29.99	17.60	31.70	27.18	28.94	4.65
17	17.60	32.30		30.80	25.90	28.42	25.05		17.60	32.30	26.68	27.16	5.24
18	17.70	32.50	26.40	29.90	24.90	29.25	22.58	31.30	17.70	32.50	26.82	27.83	4.97
20			24.60	29.90	19.90	32.02	23.14	28.89	19.90	32.02	26.41	26.75	4.61
21				31.60	24.00	30.34	24.20	29.40	24.00	31.60	27.91	29.40	3.56
22				32.60	24.90	30.42	23.90	29.72	23.90	32.60	28.31	29.72	3.74
23				31.00	23.50	31.94	21.47	29.14	21.47	31.94	27.41	29.14	4.66
24				31.20	23.90	32.08	21.54	29.28	21.54	32.08	27.60	29.28	4.64
25				32.70	24.90	32.42		30.70	24.90	32.70	30.18	31.56	3.63
26				34.20	27.60	33.26	23.82	29.28	23.82	34.20	29.63	29.28	4.24

Table 3.—Univariate statistics for salinity (ppt) at each site.

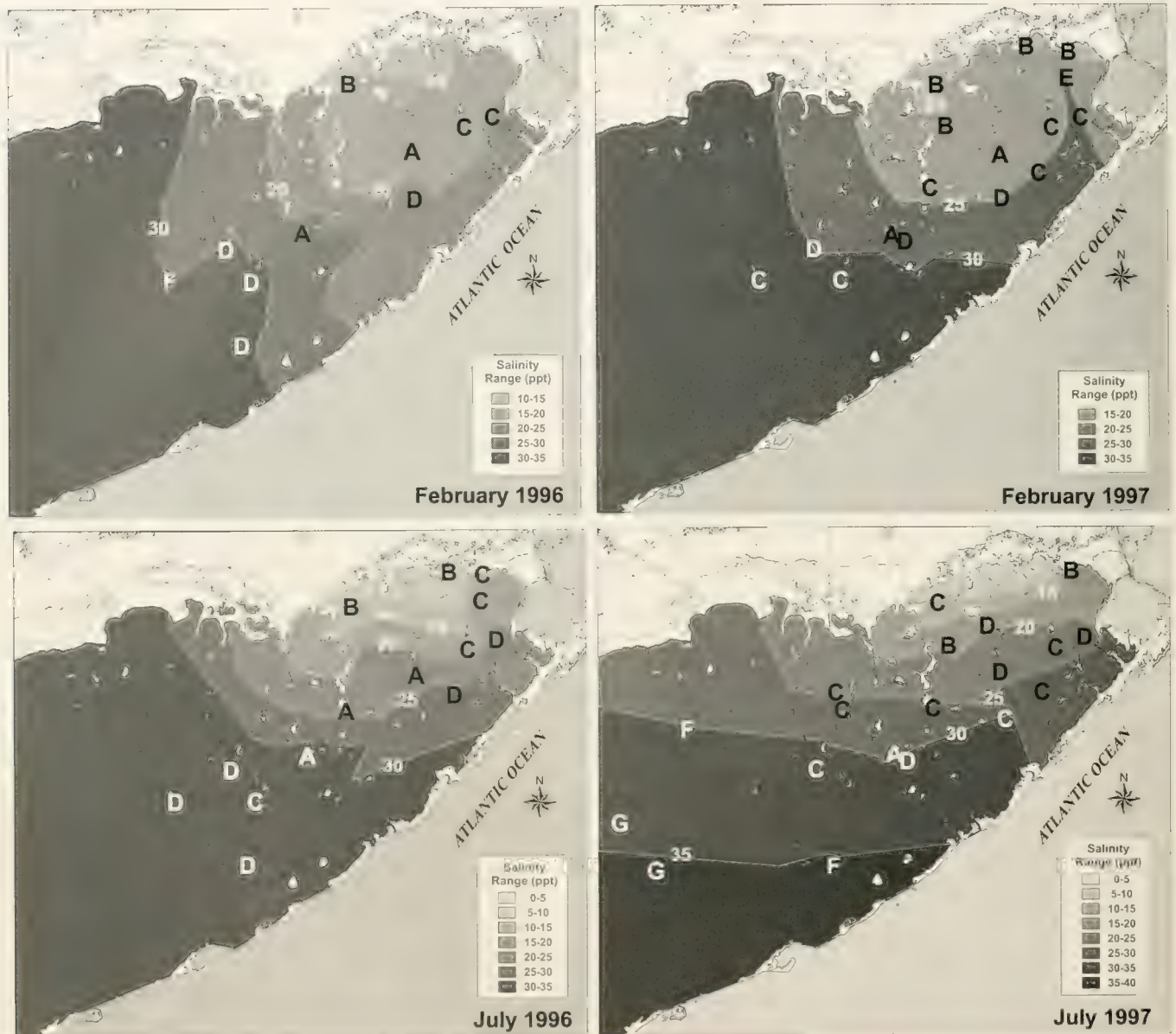
Site	2-96	7-96	2-97	7-97	2-98	7-98	2-99	7-99	All years (February and July)				
									Mini- mum	Maxi- mum	Mean	Median	Standard deviation
1	18.30	14.10	18.90	15.40	15.80	26.90	28.16	35.48	14.10	35.48	21.63	18.60	7.66
2	13.00	2.70	22.60	1.40	13.00	24.61	25.24	12.70	1.40	25.24	14.41	13.00	9.27
3	18.50	19.60	25.10	18.80	17.10	29.10	29.27	37.12	17.10	37.12	24.32	22.35	7.08
4	17.50	17.40	24.50	21.40	16.70	32.15	27.81	36.47	16.70	36.47	24.24	22.95	7.39
5	20.30	21.80	25.40	21.30	17.60	31.94	29.35	36.84	17.60	36.84	25.57	23.60	6.61
6	18.50	26.60	24.60	28.80	20.00	35.94	28.87	35.81	18.50	35.94	27.39	27.70	6.44
7	22.10	26.40	24.60	30.50	20.60	37.43	30.47	36.92	20.60	37.43	28.63	28.44	6.34
8	15.80	10.20	19.90	10.90	15.20	23.88	19.38	31.31	10.20	31.31	18.32	17.59	6.97
9	18.10	21.10	21.50	19.20	18.40	28.80	24.06	33.58	18.10	33.58	23.09	21.30	5.50
10	18.10	24.60	21.70	22.30	20.50	35.47	26.86	34.70	18.10	35.47	25.53	23.45	6.45
11	18.70	24.00	21.50	22.80	19.30	33.13	27.04	34.49	18.70	34.49	25.12	23.40	5.98
12	18.90	23.40	23.30	26.20	20.70	36.97	28.61	29.00	18.90	36.97	25.89	24.80	5.72
13	27.20	32.90	28.70	31.20	26.70	40.51	33.17	29.80	26.70	40.51	31.27	30.50	4.44
14	28	33.4	28.9	29.2		41.03	32.94	30.1	28.00	41.03	31.94	30.10	4.50
15	31.30	31.30		33.30	26.90	36.75	34.62	40.00	26.90	40.00	33.45	33.30	4.23
16	31.40	34.50	29.60	33.20	30.10	38.73	35.34	36.85	29.60	38.73	33.72	33.85	3.25
17	30.70	34.40		33.30	31.70	36.25	32.54		30.70	36.25	33.15	32.92	1.98
18	31.30	35.00	35.10	35.30	29.70	37.15	35.76	29.00	29.00	37.15	33.54	35.05	3.07
20			22.60	19.80	17.10	28.15	24.97	33.39	17.10	33.39	24.34	23.79	5.88
21				25.60	28.90	39.34	34.72	39.71	25.60	39.71	33.65	34.72	6.28
22				24.40	30.20	39.93	35.11	41.30	24.40	41.30	34.19	35.11	7.00
23				34.30	33.00	36.76	34.04	38.39	33.00	38.39	35.30	34.30	2.21
24				34.30	31.90	35.93	35.13	39.00	31.90	39.00	35.25	35.13	2.58
25				28.30	29.50	36.07		37.00	28.30	37.00	32.72	32.79	4.45
26				30.30	31.60	35.43	33.51	37.00	30.30	37.00	33.57	33.51	2.73

Table 2.—Extended.

February (all years)					July (all years)					Number of Observations	
Mini- mum	Maxi- mum	Mean	Median	Standard deviation	Mini- mum	Maxi- mum	Mean	Median	Standard deviation	Feb.	July
19.00	23.00	20.91	20.81	1.64	29.16	31.30	30.34	30.45	0.88	4	4
19.70	23.70	21.45	21.21	1.78	28.80	31.47	30.62	31.10	1.25	4	4
17.20	23.80	20.71	20.93	2.73	29.18	32.80	31.35	31.70	1.55	4	4
19.80	24.60	21.87	21.53	2.00	29.61	32.88	31.60	31.95	1.52	4	4
16.50	25.50	21.50	22.00	3.72	30.37	33.42	32.07	32.25	1.37	4	4
19.70	24.40	21.70	21.34	1.98	29.60	33.29	31.45	31.45	1.70	4	4
19.40	25.10	21.77	21.30	2.44	30.80	33.59	32.40	32.61	1.17	4	4
19.20	24.70	20.97	19.98	2.52	29.52	31.60	30.82	31.08	0.92	4	4
17.90	24.10	20.34	19.68	2.65	28.31	31.32	30.26	30.70	1.35	4	4
17.50	24.20	20.02	19.18	2.97	28.39	31.94	30.76	31.35	1.60	4	4
19.40	23.60	20.75	20.00	1.93	30.50	33.30	31.83	31.76	1.52	4	4
18.50	24.50	21.55	21.60	2.45	28.95	34.58	31.28	30.80	2.43	4	4
19.80	24.60	22.24	22.29	1.96	30.80	32.10	31.28	31.10	0.59	4	4
19.40	26.00	23.03	23.36	2.74	31.30	34.10	32.53	32.36	1.28	4	4
17.40	22.86	20.13	20.13	3.86	28.54	31.70	29.44	28.77	1.51	2	4
17.60	28.50	23.99	24.92	4.72	29.38	31.70	30.37	30.20	0.98	4	4
17.60	25.90	22.85	25.05	4.57	28.42	32.30	30.51	30.80	1.96	3	3
17.70	26.40	22.90	23.74	3.80	29.25	32.50	30.74	30.60	1.45	4	4
19.90	24.60	22.55	23.14	2.41	28.89	32.02	30.27	29.90	1.60	3	3
24.00	24.20	24.10	24.10	0.14	29.40	31.60	30.45	30.34	1.10	2	3
23.90	24.90	24.40	24.40	0.71	29.72	32.60	30.91	30.42	1.50	2	3
21.47	23.50	22.49	22.49	1.44	29.14	31.94	30.69	31.00	1.42	2	3
21.54	23.90	22.72	22.72	1.67	29.28	32.08	30.85	31.20	1.43	2	3
24.90	24.90	—	—	—	30.70	32.70	31.94	32.42	1.08	1	3
23.82	27.60	25.71	25.71	2.67	29.28	34.20	32.25	33.26	2.61	2	3

Table 3.—Extended.

February (all years)					July (all years)					Number of Observations	
Mini- mum	Maxi- mum	Mean	Median	Standard deviation	Mini- mum	Maxi- mum	Mean	Median	Standard deviation	Feb.	July
15.80	28.16	20.29	18.60	5.42	14.10	35.48	22.97	21.15	10.13	4	4
13.00	25.24	18.46	17.80	6.40	1.40	24.61	10.35	7.70	10.76	4	4
17.10	29.27	22.49	21.80	5.71	18.80	37.12	26.16	24.35	8.68	4	4
16.70	27.81	21.63	21.00	5.41	17.40	36.47	26.86	26.78	8.94	4	4
17.60	29.35	23.16	22.85	5.24	21.30	36.84	27.97	26.87	7.68	4	4
18.50	28.87	22.99	22.30	4.70	26.60	35.94	31.79	32.31	4.80	4	4
20.60	30.47	24.44	23.35	4.34	26.40	37.43	32.81	33.71	5.31	4	4
15.20	19.90	17.57	17.59	2.41	10.20	31.31	19.07	17.39	10.30	4	4
18.10	24.06	20.52	19.95	2.82	19.20	33.58	25.67	24.95	6.71	4	4
18.10	26.86	21.79	21.10	3.70	22.30	35.47	29.27	29.65	6.79	4	4
18.70	27.04	21.64	20.40	3.80	22.80	34.49	28.61	28.57	6.06	4	4
18.90	28.61	22.88	22.00	4.23	23.40	36.97	28.89	27.60	5.85	4	4
26.70	33.17	28.94	27.95	2.94	29.80	40.51	33.60	32.05	4.78	4	4
28.00	32.94	29.95	28.90	2.63	29.20	41.03	33.43	31.75	5.38	3	4
26.90	34.62	30.94	31.30	3.87	31.30	40.00	35.34	35.03	3.84	3	4
29.60	35.34	31.61	30.75	2.60	33.20	38.73	35.82	35.68	2.46	4	4
30.70	32.54	31.65	31.70	0.92	33.30	36.25	34.65	34.40	1.49	3	3
29.70	35.76	32.97	33.20	2.93	29.00	37.15	34.11	35.15	3.54	4	4
17.10	24.97	21.56	22.60	4.04	19.80	33.39	27.11	28.15	6.85	3	3
28.90	34.72	31.81	31.81	4.12	25.60	39.71	34.88	39.34	8.04	2	3
30.20	35.11	32.66	32.66	3.47	24.40	41.30	35.21	39.93	9.39	2	3
33.00	34.04	33.52	33.52	0.74	34.30	38.39	36.48	36.76	2.06	2	3
31.90	35.13	33.52	33.52	2.28	34.30	39.00	36.41	35.93	2.39	2	3
29.50	29.50	—	—	—	28.30	37.00	33.79	36.07	4.78	1	3
31.60	33.51	32.56	32.56	1.35	30.30	37.00	34.24	35.43	3.50	2	3



Text-figure 3.—Maps showing 5 ppt salinity gradients and the prominent cluster designations from the presence-absence Q-mode analysis for the sampling periods from February 1996 through July 1999. Contours are primarily based on our own salinity measurements, however, in areas of sparse sampling we utilized data from Halley (<http://sofia.usgs.gov/projects/circulation>) to fill in the gaps.

$$H' = -\sum_{i=1}^s p_i \log p_i$$

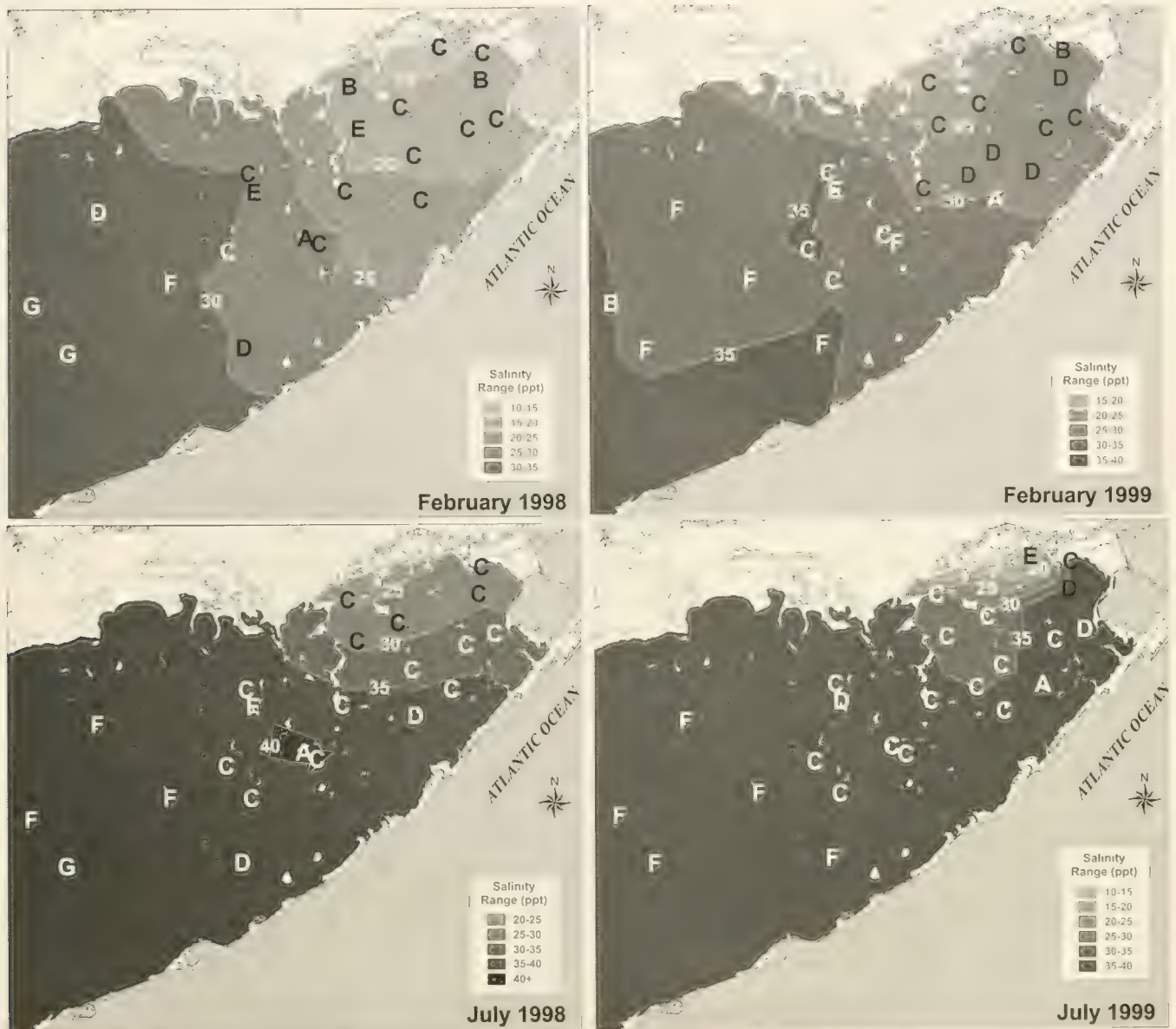
where s is the number of species of known proportions ($p_1, p_2, p_3, \dots, p_s$) (see Ludwig and Reynolds, 1988, p. 92, for complete explanation).

RESULTS

MODERN ENVIRONMENTAL DATA

Text-figure 2 shows seasonal and annual variations recorded in temperature and salinity at our monitoring sites in Florida Bay. These measurements show that

bay-wide salinity is less variable in the winter (dry) season than during the summer (wet) season, but the opposite is true for water temperature. Recorded winter water temperatures have varied more than 10°C from one year to the next, ranging from a low of 16.5°C (site 5, 2/96) to a high of 28.5°C (site 16, 2/97). Summer water temperatures have ranged from a low of 28.3°C (site 9, 7/99) to a high of 34.6°C (site 12, 7/98). Seasonal standard deviations for the period of record are relatively low for water temperatures at each site, and water temperatures do not display a strong geographic gradient (Table 2).



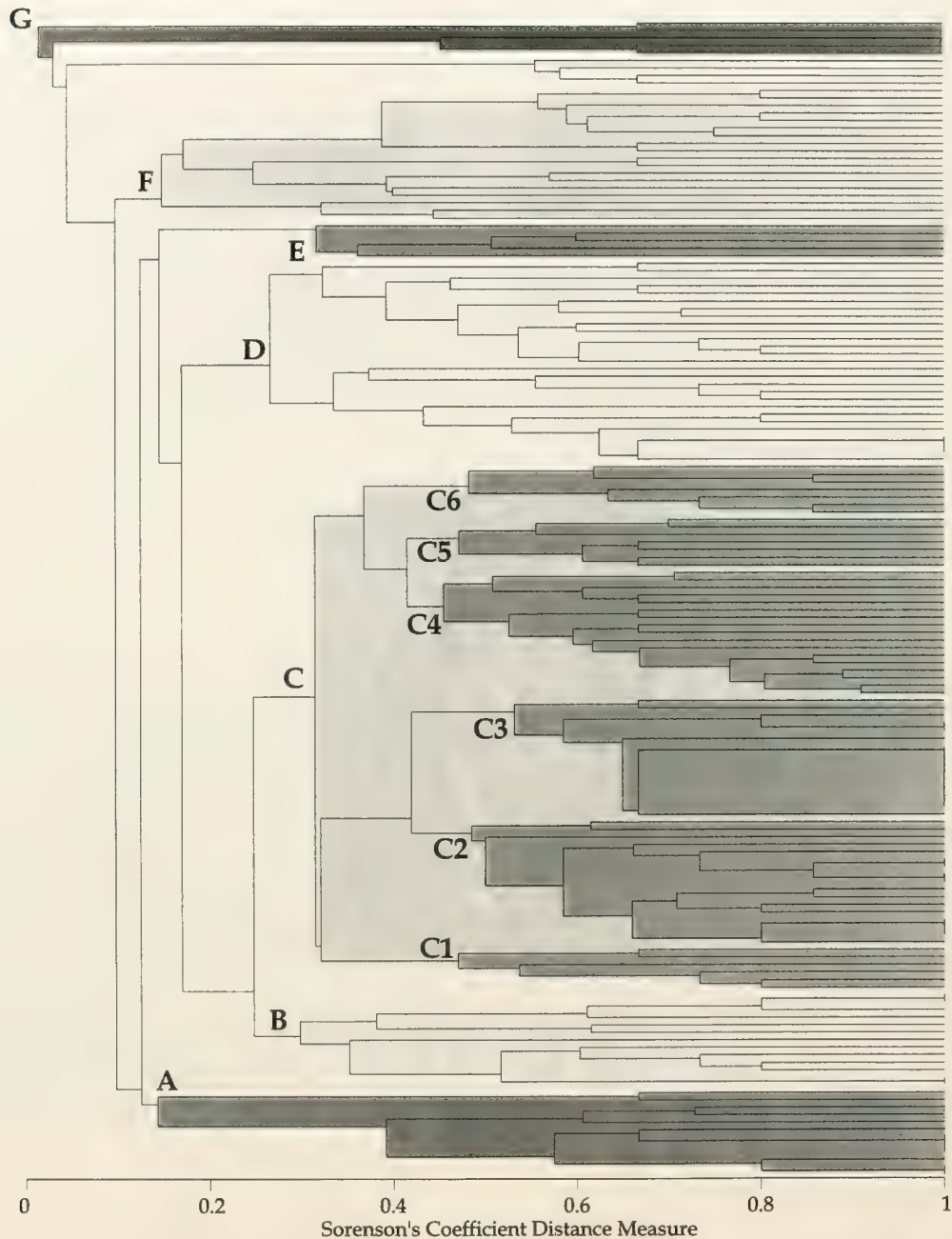
Text-figure 3.—Continued.

In contrast to temperature, salinity does display a strong geographic gradient. Text-figure 3 illustrates seasonal changes in salinity and Table 3 lists standard deviations calculated for each site. In general, standard deviations for salinity decrease as you move to the south and west in the bay, indicating more stable salinity on a seasonal and annual basis. Summer salinity standard deviation values are significantly higher at most sites than the winter values. Salinity at three sites (1, 2, and 8) in the northern transition zone has varied over 20 ppt during the July sampling period from 1996–1999, compared to winter variations at the same sites of 5–12 ppt. Bay-wide salinity has ranged from

a low of 1.4 ppt (site 2, 7/97) to a high of 41.3 ppt (site 22, 7/99).

MODERN MOLLUSCAN PRESENCE-ABSENCE DATA

An unweighted pair-group method (UPGM) dual-cluster analysis, using Sorenson's coefficient on the modern presence-absence faunal dataset (rares deleted), produced the clusters seen in Text-figures 4 and 5. The dual clustering method (Kovach, 1989, 1995) allows direct comparison between the separate Q-mode and R-mode analyses. Q-mode analysis produced seven primary clusters, grouping the modern sample sites based on species found alive at those

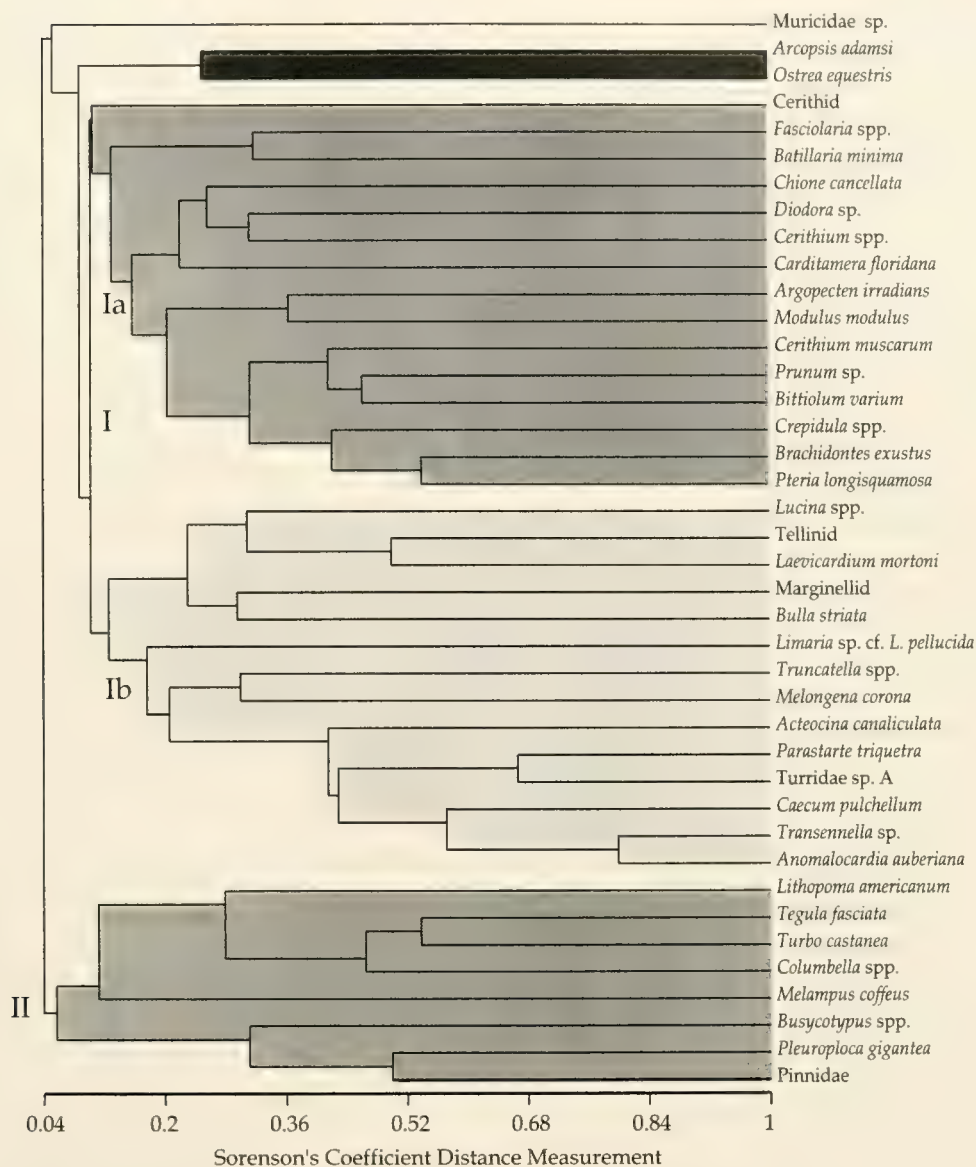


Text-figure 4.—Q-mode cluster of presence-absence data from modern monitoring sites. Cluster was generated through MVSP statistical package (Kovach Computing Services, MVSP Plus, version 3.1) using unweighted paired group method, average-linkage (UPGMA), with Sorensen's Coefficient distance measurement, dual clustering procedure, and random input order. Full data matrix sorted in dendrogram order and labeled clusters can be viewed at <http://flaeohist/database/Reference/synthesis>. Table 4 indicates which species are responsible for the clusters seen.

sites. An examination of the clusters and the associated data matrix, sorted in dendrogram order, indicated which fauna are responsible for the clustering of sample sites seen. Text-figure 3 shows the distribution of the clusters by sampling period.

Cluster A groups samples from sites 6, 7, 11, 12 and 14 in eastern and central Florida Bay. The occur-

rence of *Batillaria minima* and/or *Melongena corona* defines this cluster; constancy (C) and fidelity (F) for *Batillaria minima* equal 83.3 and 80.0 and for *Melongena corona* 50.0 and 70.3 (Table 4). *Fasciolaria* spp. and *Truncatella* spp. also have high fidelity values for this cluster (Table 4). Sites in cluster A can be characterized as having a subenvironment with shallow



Text-figure 5.—R-mode cluster of presence-absence data from modern monitoring sites. Cluster analysis and full data matrix as in Text-figure 4.

(<20 cm) water depth in relatively close proximity to mangrove islands, sparse vegetation (<20% *Halodule*, scattered *Thalassia* may be present), and soft, “gelatinous” calcareous mud is typical (799-6 is an exception). Average salinity for the cluster is 28.4 ppt, and the range is 18.7–41.0 ppt. Average observed faunal richness² at sample sites in cluster A is three, with a maximum of six faunal groups seen alive during one observation period.

² Faunal richness for the modern presence-absence database is a measure of the number of faunal groups observed alive at a site during one field season. The fauna are frequently grouped into genera and occasionally into broader categories (e.g., Marginellids), so

Cluster B is defined by the presence of *Ostrea equestris* ($C = 76.9$, $F = 70.5$) and/or *Arcopsis adamsi* ($C = 46.2$, $F = 87.6$), with *Brachidontes exustus* present in nine of the thirteen samples in this cluster (Table 4). The sample sites (1, 2, 3, 8, 9, and 24) are geographically widespread, encompassing the northern transitional zone, eastern, and western portions of

this is not “species” richness in the usual sense. In addition, the observation and recording process is definitely biased towards epifaunal mollusks, and so this is not meant to be a measure of the true richness of the environment. However, because the same categories were used at all sites and similar methods, we feel it is a basis for comparing the faunal richness from one site and one observation period to another.

Table 4.—Occurrence (O), constancy (C), and fidelity (F) values for each taxon in each cluster from the presence-absence cluster analysis. Taxa are sorted in R-mode dendrogram order. Class designation: P = Pelecypoda, G = Gastropoda.

R-mode Cluster Class	Faunal Group	Q-mode Cluster																	
		A			B			C			D			E			F		
		O	C	F	O	C	F	O	C	F	O	C	F	O	C	F	O	C	F
II	P Pinnidae	—	—	—	—	—	—	—	—	—	1	3.7	5.0	—	—	—	2	11.1	14.9
	G <i>Pleuroploca gigantea</i> (Kiener)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	2	40.0
	G <i>Busycotypus</i> spp.	—	—	—	—	—	—	1	1.4	5.3	—	—	—	—	—	—	1	5.6	20.6
	G <i>Melampus coffeus</i> (Linnaeus)	—	—	—	—	—	—	—	—	—	2	7.4	100.0	—	—	—	—	—	—
	G <i>Columbella</i> spp.	—	—	—	—	—	—	6	8.6	12.0	2	7.4	10.4	—	—	—	10	55.6	77.7
	G <i>Turbo castanea</i> Gmelin	—	—	—	1	7.7	7.8	2	2.9	2.9	5	18.5	18.7	—	—	—	9	50.0	50.5
	G <i>Tegula fasciata</i> (Born)	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	7	38.9	66.0
	G <i>Lithopoma americanum</i> (Gmelin)	—	—	—	—	—	—	1	1.4	2.5	1	3.7	6.6	—	—	—	2	11.1	19.8
IIb	P <i>Anomalocardia auferiana</i> (d'Orbigny)	—	—	—	1	7.7	17.3	4	5.7	12.8	—	—	—	1	20.0	44.9	2	11.1	25.0
	P <i>Transennella</i> sp.	—	—	—	1	7.7	37.7	5	7.1	35.0	—	—	—	—	—	—	1	5.6	27.2
	G <i>Caecum pulchellum</i> Stimpson	—	—	—	1	7.7	72.9	2	2.9	27.1	—	—	—	—	—	—	—	—	—
	G Turridae sp. A	—	—	—	—	—	—	2	2.9	100.0	—	—	—	—	—	—	—	—	—
	P <i>Parastarte triquetra</i> (Conrad)	—	—	—	—	—	—	4	5.7	100.0	—	—	—	—	—	—	—	—	—
	G <i>Acteocina canaliculata</i> (Say)	—	—	—	—	—	—	2	2.9	100.0	—	—	—	—	—	—	—	—	—
	G <i>Melongena corona</i> (Gmelin)	6	50.0	70.3	—	—	—	7	10.0	14.1	3	11.1	15.6	—	—	—	—	—	—
	G <i>Truncatella</i> spp.	1	8.3	44.1	1	7.7	40.7	2	2.9	15.1	—	—	—	—	—	—	—	—	—
	P <i>Limaria</i> sp. cf. <i>L. pellucida</i> (C.B. Adams)	—	—	—	—	—	—	2	2.9	23.6	1	3.7	30.6	—	—	—	1	5.6	45.9
	G <i>Bulla striata</i> Bruguière	—	—	—	—	—	—	9	12.9	30.5	1	3.7	8.8	1	20.0	47.5	1	5.6	13.2
	G Marginellid	1	8.3	8.9	—	—	—	5	7.1	7.6	5	18.5	19.7	3	60.0	63.8	—	—	—
	P <i>Laevicardium mortoni</i> (Conrad)	1	8.3	7.1	—	—	—	6	8.6	7.3	—	—	—	5	100.0	85.5	—	—	—
	P Tellinid	—	—	—	—	—	—	2	2.9	6.7	—	—	—	2	40.0	93.3	—	—	—
	P <i>Lucina</i> spp.	—	—	—	—	—	—	—	—	—	—	—	—	2	40.0	100.0	—	—	—
Ia	P <i>Pteria longisquamosa</i> (Dunker)	2	16.7	8.9	1	7.7	4.1	36	51.4	27.6	23	85.2	45.7	1	20.0	10.7	1	5.6	3.0
	P <i>Brachidontes exustus</i> (Linnaeus)	3	25.0	9.4	9	69.2	26.1	66	94.3	35.5	4	14.8	5.6	2	40.0	15.1	4	22.2	8.4
	G <i>Crepidula</i> spp.	1	8.3	5.0	3	23.1	13.9	26	37.1	22.4	5	18.5	11.2	1	20.0	12.1	7	38.9	23.4
	G <i>Bittium varium</i> (Pfeiffer)	—	—	—	2	15.4	27.4	22	31.4	56.0	1	3.7	6.6	—	—	—	1	5.6	9.9
	G <i>Prunum</i> sp.	2	16.7	24.7	2	15.4	22.8	21	30.0	44.4	—	—	—	—	—	—	1	5.6	8.2
	G <i>Cerithium muscarum</i> Say	—	—	—	—	—	—	9	12.9	69.8	—	—	—	—	—	—	1	5.6	30.2
	G <i>Modulus modiolus</i> (Linnaeus)	—	—	—	1	7.7	10.6	5	7.1	9.9	14	51.9	71.8	—	—	—	1	5.6	7.7

Table 4.—Continued.

R-mode Cluster Class	Faunal Group	Q-mode Cluster																	
		A			B			C			D			E			F		
		O	C	F	O	C	F	O	C	F	O	C	F	O	C	F	O	C	F
Ia (cont'd)	<i>Argopecten irradians</i> (Lamarck)	—	—	—	1	7.7	11.7	11	15.7	23.8	10	37.0	56.1	—	—	—	1	5.6	8.4
P	<i>Carditamera floridana</i> Conrad	—	—	—	1	7.7	15.4	1	1.4	2.9	2	7.4	14.9	—	—	—	6	33.3	66.9
G	<i>Cerithium</i> spp.	—	—	—	—	—	—	9	12.9	16.6	4	14.8	19.1	—	—	—	9	50.0	64.4
G	<i>Diodora</i> sp.	—	—	—	—	—	—	5	7.1	15.0	1	3.7	7.8	1	20.0	42.1	3	16.7	35.1
P	<i>Chione cancellata</i> (Lin- naeus)	—	—	—	—	—	—	10	14.3	26.9	3	11.1	20.9	—	—	—	5	27.8	52.2
G	<i>Batillaria minima</i> (Gme- lin)	10	83.3	80.0	—	—	—	12	17.1	16.5	1	3.7	3.6	—	—	—	—	—	—
G	<i>Fasciolaria</i> spp.	5	41.7	48.0	—	—	—	7	10.0	11.5	5	18.5	21.3	—	—	—	3	16.7	19.2
G	<i>Cerithid</i>	—	—	—	1	7.7	34.6	5	7.1	32.1	2	7.4	33.3	—	—	—	—	—	—
I	<i>Ostrea equestris</i> Say	—	—	—	10	76.9	70.5	2	2.9	2.6	1	3.7	3.4	1	20.0	18.3	1	5.6	5.1
P	<i>Arcopsis adamsi</i> (Dall)	—	—	—	6	46.2	87.6	2	2.9	5.4	1	3.7	7.0	—	—	—	—	—	—
G	Muricidae sp.	—	—	—	—	—	—	2	2.9	20.5	3	11.1	79.5	—	—	—	—	—	—
Outlier	Total number of samples/ cluster	—	12	—	—	13	—	70	—	—	3	27	—	5	—	—	18	—	5

Florida Bay. The common characteristic of these sites is the presence of wood (mangrove roots, driftwood, or pilings) or exposed limestone bedrock that provides an attachment-point for the cemented *Ostrea equestris*, or bysally attached *Arcopsis adamsi*. Salinity values for the cluster range from 2.7–35.1 ppt, and the average is 18.6 ppt. A maximum of seven faunal groups were found alive at sites in cluster B, and the average observed faunal richness is three.

Cluster C comprises the largest group of samples (70) from sites 1–17, and 20–22 in the northern transitional, eastern and central portions of Florida Bay. The nearly ubiquitous occurrence of *Brachidontes exustus* (66 of our 70 samples, C = 94.3, F = 35.5) distinguishes this cluster (Table 4). Within the larger cluster C are six smaller groupings, characterized by species that co-occur with *Brachidontes exustus*. Average salinity for cluster C is 28.1 ppt, and the range is 10.9–41.3 ppt. The environments represented by the 20 sites in this cluster are varied, including mud banks, mangrove islands, open basins, and channels, but all have at least some subaquatic vegetation present. Sites within cluster C attain the highest values for observed faunal richness; the average is five and the maximum value is 20.

Cluster D includes samples from eastern, central, western, and Atlantic transition zone sites (3, 5–7, 10, 11, 13, 15–18, 20, 21, and 26). The occurrence of *Pteria longisquamosa* [= *Pinctada radiata* Turney and Perkins] (C = 85.2, F = 45.7) distinguishes cluster D; and the occurrence of *Modulus modiolus* (C = 51.9, F = 71.8) is significant (Table 4). The environments represented by these samples can generally be characterized by the presence of healthy *Thalassia* beds (exceptions, 6, 10, and 26). Average salinity for the samples is 29.9 ppt and the range is 19.8–39.7 ppt. Observed faunal richness at sites in cluster D averages four, and the maximum value is eleven.

A small group of five samples from the northern transitional zone, and eastern and central Florida Bay (sites 2, 3, 9, and 21) constitute Cluster E. The presence of *Laevicardium murtoni* (C = 100, F = 85.5) distinguishes this cluster (Table 4). All of the sites have a subenvironment with exposed substrate and sparse vegetation. The average salinity for the cluster is 24.0 ppt and the range is 12.7–34.7 ppt. Observed faunal richness ranges from 2–6, and the average is 4.

Cluster F includes two distinct sub-clusters, one distinguished by the co-occurrence of *Turbo castanea* (C = 50, F = 50.5), *Tegula fasciata* (C = 38.9, F = 66) and *Columbella* spp. (C = 55.6, F = 77.7), the other by *Columbella* spp., *Cerithium* spp. (C = 50, F = 64.4), *Chione cancellata* (C = 27.8, F = 52.2) and *Carditamera floridana* (C = 33.3, F = 66.9) (Table

4). The cluster includes sites from the central, western, Gulf transition, and Atlantic transition zones of Florida Bay (13, 17, 18, 21, 23, 24, and 26). The sites can be characterized as having lush subaquatic vegetation and bare sediment areas available. Average salinity for cluster F is 34.6 ppt, and the range is 29.0–39.3 ppt. Average observed faunal richness is four and the maximum value is eight for the sites in cluster F.

Cluster G comprises five samples from the westernmost sites (23 and 24) in the Gulf transition zone. *Pinnidae* ($C = 60$, $F = 80.2$), and *Pleuroploca gigantea* ($C = 40$, $F = 100$) define this cluster (Table 4). Average salinity is 34.1 ppt, and the range is 31.9 to 36.8 ppt. These sites are predominantly calcareous sand bars, with lush beds of mixed subaquatic vegetation present, including *Thalassia*, *Halodule*, *Syringodium*, and many species of calcareous algae, and macro-benthic red, green and brown algae. The sites at cluster G have the lowest observed faunal richness, with an average of two and a maximum of five faunal groups found alive at the sites.

R-mode analysis produced two primary divisions of the faunal categories, based on the samples in which they are found (Text-fig. 5). In general, fauna in cluster I tolerate a wide range of conditions and can be found in the northern transitional, eastern, central and western portions of the bay. Fauna in cluster I were found alive in salinities ranging from 2.7–41.3 ppt. The remainder of the faunal groups fall into cluster II, with the exception of *Muricidae* sp., a rare species that is an outlier on the dendrogram. Cluster II groups fauna that are typically found in the western portions of the Bay, or at sites with near normal marine salinities. The average salinity recorded at sites where fauna from cluster II are found is 33.3 ppt and the range is 17.6–40.0 ppt. The exception in cluster II is *Melampus coffeus*. The presence of *Melampus* is indicative only of the presence of a supratidal environment and the presence of mangroves.

MODERN VEGETATION SAMPLE DATA

Sixteen vegetation samples and one surficial mud sample were analyzed from sites 8, 12, 13, and 20, collected in February and July 1998.¹ *Brachidontes exustus* and *Bittium varium* account for 95% (10,981 individuals) of the 35 molluscan faunal groups found alive in the samples from all four sites. These two species were most frequently found in polytypic subaquatic vegetation samples, including *Thalassia* and macro-benthic algae. *Crepidula* spp., *Cerithium muscarum*, *Pteria longisquamosa* and *Prunum* spp. combined constitute only 2.25% (260 individuals) of the living fauna collected.

MODERN PUSH CORE DATA

Twenty-eight push core samples were analyzed from sites 8, 12, 13, and 20, collected in February and July beginning in 1995.¹ The push core samples represent death assemblages at each site, and thus the push core data provide a link between modern living assemblage data and down-core assemblages from the core data set. Two cluster analyses were done (Text-fig. 6); one included all specimens, regardless of preservation; the other was limited to only pristine and broken shells. The purpose was to contrast the death assemblage at each site with the living or recently expired fauna. The two clusters produced similar results. All samples from site 8 formed a distinct cluster in both analyses. In general, samples tended to cluster with other samples from the same site in both analyses.

Brachidontes exustus and *Bittium varium* are among the four most abundant species in the push cores at all four sites (8, 12, 13, and 20), based on the cumulative data. When the individual push core data are examined for each site, *Bittium varium* is among the four most abundant species and *Brachidontes exustus* is among the six most abundant species. *Transennella* sp. is among the four most abundant species at sites 12, 13, and 20, and *Crepidula* spp. at sites 12 and 13. The discrete clustering of site 8 can be explained by the prominence of Hydrobiidae, *Truncatella bilabiata*, and *Anomalocardia auberiana*.

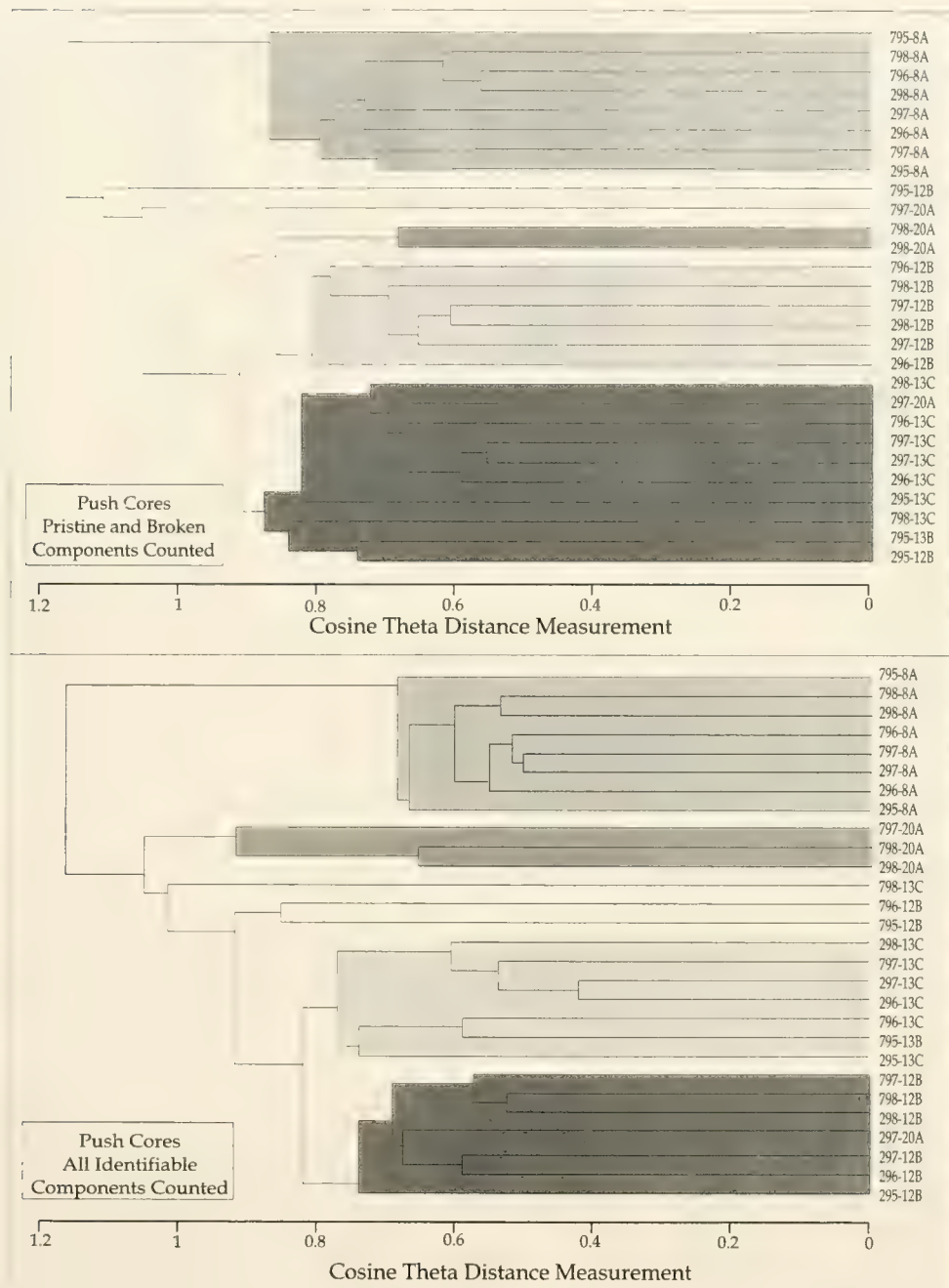
HISTORICAL PISTON CORE DATA

Details of the individual core analyses have been previously published (Brewster-Wingard *et al.*, 1997, 1998a, 1998b; Brewster-Wingard and Ishman, 1999; Ishman *et al.*, 1996; Wingard *et al.*, 1995).³ Text-figures 7–10 illustrate the down-core distribution of key species identified in the modern presence-absence data analysis and in previous core analyses. Shannon's diversity index, faunal evenness, the number of faunal groups, and the number of specimens present are also shown on the down-core plots (Text-figs. 7–10). The age model for cores 6A and 19B is based on sedimentation rates calculated from ²¹⁰Pb analysis. The rate for core 6A is 0.75 cm/yr $\pm$ 0.08 and for core 19B is 1.27 cm/yr $\pm$ 0.08 (Holmes, *et al.*, this volume).

COMPILED DATA SET

Percent abundance data were compiled from the modern vegetation samples and push cores from sites 8, 12, 13, and 20, and from the corresponding piston cores. The compiled database was analyzed using the unweighted pair-group method (UPGM) dual-cluster

³ All open-file reports and data tables for each core are available on line at <http://sofia.usgs.gov/flaecoHist>.



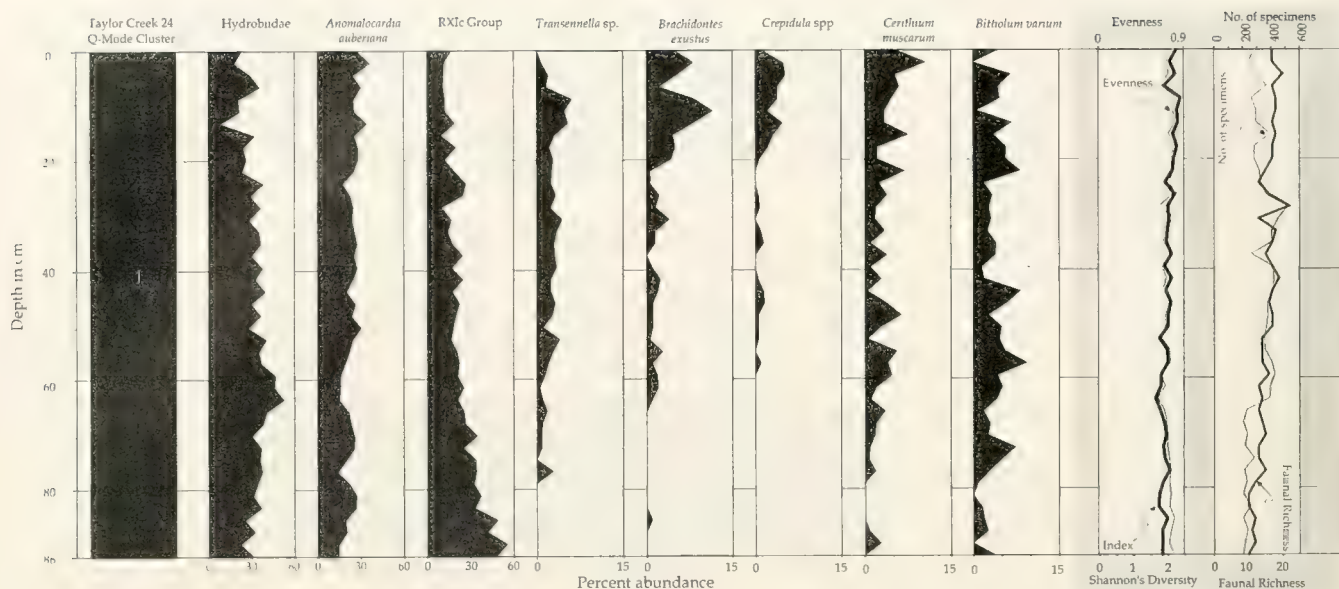
Text-figure 6.—Q-mode cluster of push-core data from modern monitoring sites. Top cluster illustrates the results when only the pristine and broken (retaining original material and more than 50% of shell) material are included. Bottom cluster includes all identifiable molluscan components. Clusters were generated using MVSP statistical package (Kovach Computing Services, MVSP Plus, version 3.1) on log-ratio transformed and centered percent abundance data, using unweighted paired group method, average-linkage (UPGMA), with cosine theta distance measurement, dual clustering procedure, and random input order.

procedure, with cosine theta distance measures on a log-transformed data matrix (Text-figs. 11 and 12). Q-mode analysis produced three main clusters, grouping the individual samples based on the faun they contain. Faunal groups responsible for the Q-mode clusters

were determined by an examination of the associated data matrix, sorted in dendrogram order.⁴

Cluster J is divided into two very distinct compo-

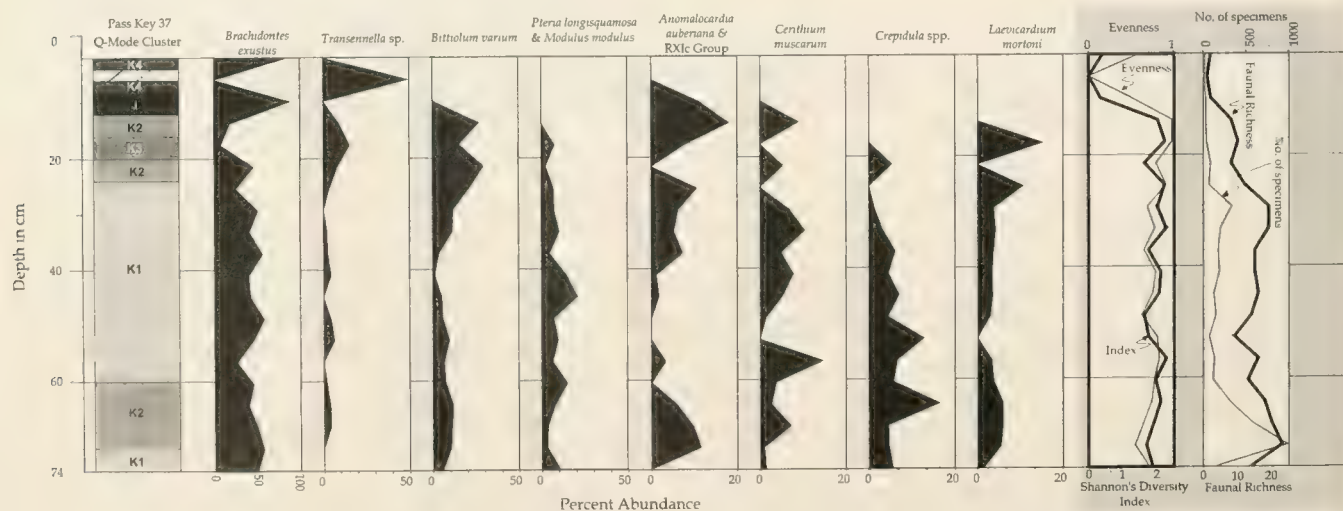
⁴ See footnote 1, p. 202.



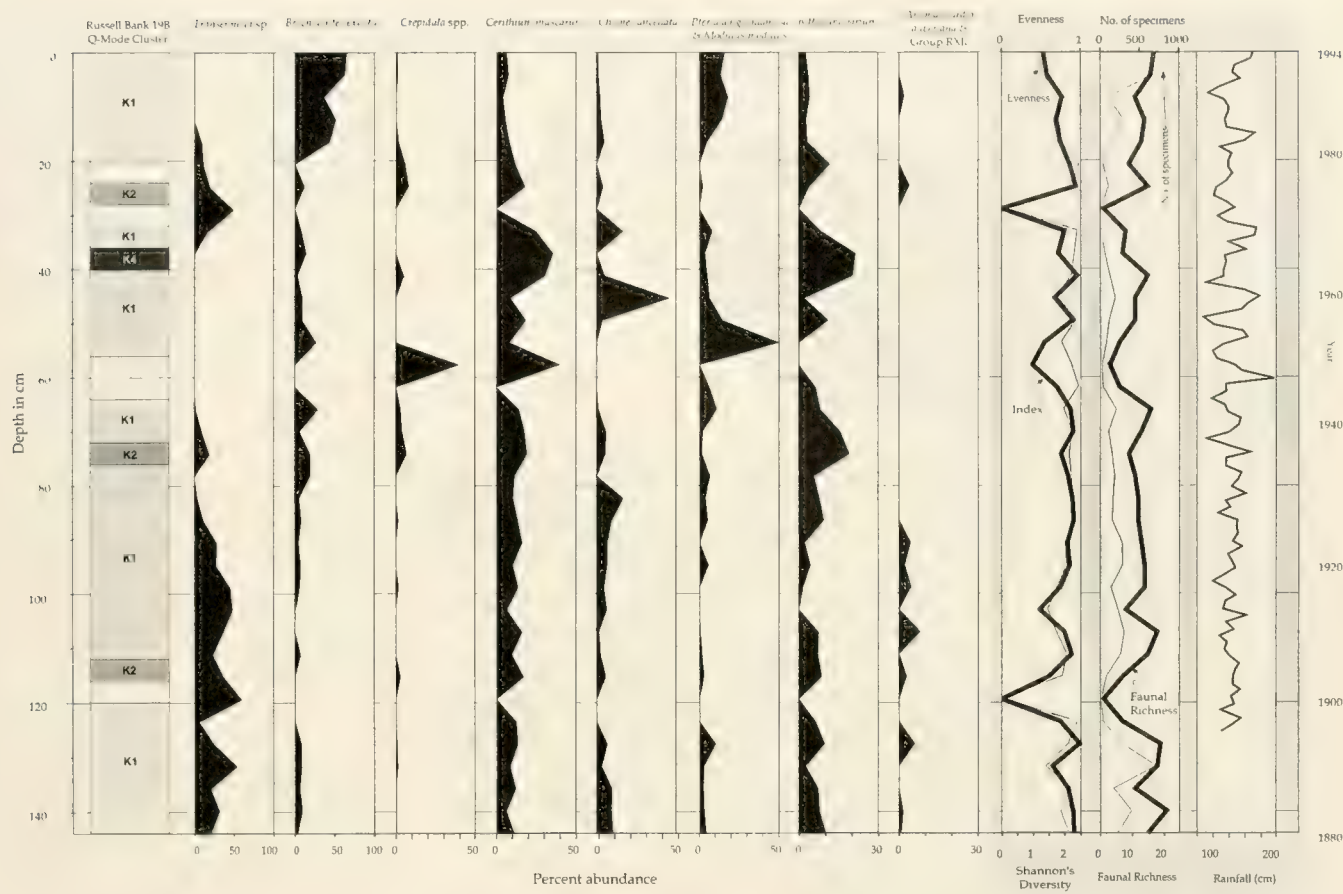
Text-figure 7.—Down-core changes in core T24 from the mouth of Taylor Creek in Little Madeira Bay. Columns illustrate changes in Q-mode clusters (see Text-fig. 11), significant molluscan fauna (shown as percent abundance), Shannon's diversity index, evenness, number of faunal groups, and number of individual specimens. RXIc group refers to the R-mode cluster shown in Text-figure 12; this group is composed primarily of species that prefer salinities less than 18 ppt. Depth is shown in cm.

nents (Text-fig. 11). Cluster J1 is primarily composed of modern push core samples, the majority of these from site 8. Cluster J2 is exclusively composed of samples from core T24. A diverse faunal assemblage, blending components of R-mode clusters XIa and XIc (Text-fig. 12) defines cluster J. *Anomalocardia auberiana* ($C = 93.4$, $F = 65.4$), *Acteocina canaliculata* (C

$= 93.4$, $F = 69$), and Hydrobiidae ($C = 85.2$, $F = 92.9$) are the dominant fauna in cluster J, and *Polydora maritima*, and *Cerithidea* spp. are characteristic (Table 5). Cluster J1 is further distinguished by a group of species from R-mode cluster XII (*Odostomia* spp., *Prunum* sp., *Schwartziella catesbyana*, *Bittolum varium* juv., and *Truncatella* spp.). A number of faunal



Text-figure 8.—Down-core changes in core PK37 from south of Pass Key in eastern Florida Bay. Columns illustrate changes in Q-mode clusters (see Text-fig. 11), significant molluscan fauna (shown as percent abundance), Shannon's diversity index, evenness, number of faunal groups, and number of individual specimens. RXIc group refers to the R-mode cluster shown in Text-figure 12; this group is composed primarily of species that prefer salinities less than 18 ppt. Depth is shown in cm.

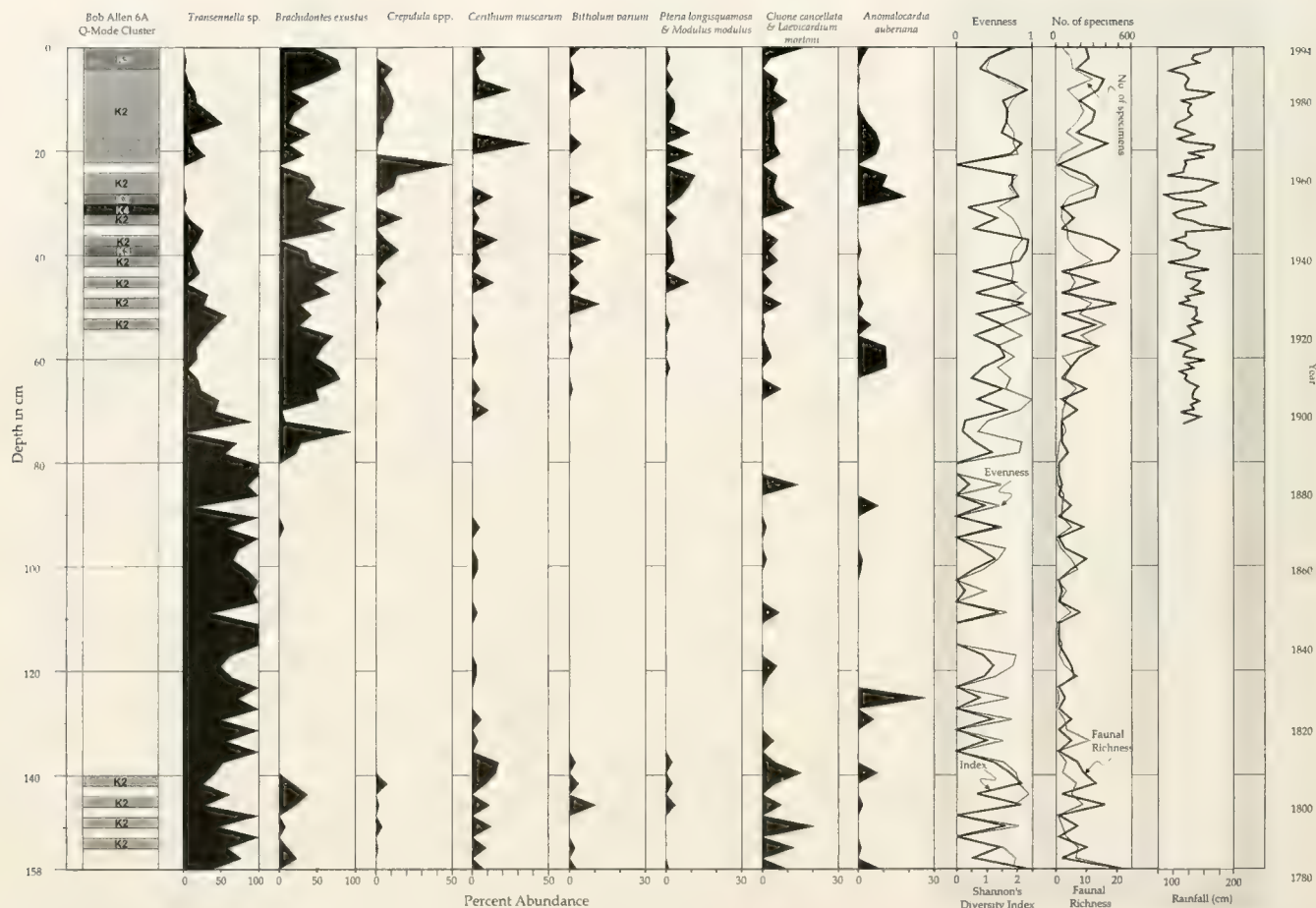


Text-figure 9.—Down-core changes in core RB19B from Russell Bank in eastern Florida Bay. Columns illustrate changes in Q-mode clusters (see Text-fig. 11), significant molluscan fauna (shown as percent abundance), Shannon's diversity index, evenness, number of faunal groups, and number of individual specimens. Rainfall data is compiled from NOAA NCDC website <http://www.ncdc.noaa.gov/>. RXIc group refers to the R-mode cluster shown in Text-figure 12; this group is composed primarily of species that prefer salinities less than 18 ppt. Depth is shown in cm. Age is based on ^{210}Pb analysis (Holmes *et al.*, this volume).

groups occur in cluster J that are absent in other clusters ($F = 100$, Table 5), indicating cluster J represents a relatively unique and diverse assemblage. These results are consistent with the analysis of the push cores (Text-fig. 6); site 8 push cores formed a distinct cluster, separate from the other sites. The average diversity measures for cluster J are relatively high: Shannon's diversity index is 2.03; evenness is 0.74; and faunal richness is 16.8.

Cluster K represents a mixture of samples from cores 6A, 19B, and 37, with modern push core samples from sites 12, 13, and 20, and modern vegetation samples from sites 8, 12, 13, and 20. The common unifying element for cluster K is the presence and relatively high abundance of *Brachidontes exustus* in all but a few samples (average abundance 32.13%, $C = 98.1$). A number of species are present in a high percentage of samples (Table 5), but at relatively low percent abundances, forming a distinct and diverse assemblage

defined by R-mode clusters XIa and XIb. Cluster K can be subdivided into four components (Text-fig. 11). Cluster K1 is predominantly samples from cores 19B and 37. In addition to *Brachidontes exustus*, cluster K1 is defined by the presence of *Bittium varium*, *Cerithium muscarum* juv., and Rissoidea. The core samples in K1 can be further divided based on the abundance of *Pterisquamus*, *Modiolus modiolus* and marginellids in K1a and *Transennella* sp., *Chione cancellata*, *Olivella pusilla*, and *Vermicularia* sp. in K1b. Cluster K2 is faunally diverse and contains a mixture of vegetation, push core and core samples primarily defined by R-mode cluster XIa species, including *Laevicardium mortoni* and *Tellina* spp., which distinguishes this cluster from K1. The occurrence of *Cerithidea* spp. with abundant *Brachidontes exustus* isolates the four samples that constitute cluster K3. Cluster K4 is primarily vegetation samples and is lower in diversity than the rest of cluster K. *Bittium varium*,



Text-figure 10.—Down-core changes in core BA6A from Bob Allen mudbank in central Florida Bay. Columns illustrate changes in Q-mode clusters (see Text-fig. 11), significant molluscan fauna (shown as percent abundance), Shannon's diversity index, evenness, number of faunal groups, and number of individual specimens. Rainfall data were compiled from NOAA NCDC website <http://www.ncdc.noaa.gov/>. Depth is shown in cm. Age is based on ²¹⁰Pb analysis (Holmes *et al.*, this volume).

B. varium juv. and *Brachidontes exustus* dominate cluster K4. Average Shannon's diversity index for cluster K is 1.79; evenness is 0.71; and faunal richness is 14.3.

Cluster L is predominantly samples from the lower portion of core 6A. The prevalence of *Transennella* sp. (C = 100, F = 39.7) defines this cluster (Table 5). Average abundance of *Transennella* sp. in samples from cluster L is 64.21%. Measures of diversity for cluster L are significantly lower than for clusters J and

K. Average values for cluster L are 0.60 for Shannon's diversity index, 0.45 for evenness, and 3.7 for faunal richness.

DISCUSSION

MODERN ENVIRONMENTAL DATA

Our temperature and salinity measurements are in agreement with climatologic and oceanographic data gathered during the same time period in Florida Bay

Text-figure 11.—Q-mode cluster of compiled data (cores, push-cores, and vegetation samples). Clusters were generated using MVSP statistical package (Kovach Computing Services, MVSP Plus, version 3.1) on log-ratio transformed and centered percent abundance data, using unweighted paired group method, average-linkage (UPGMA), with cosine theta distance measurement, dual clustering procedure, and random input order. Full data matrix sorted in dendrogram order and labeled clusters can be viewed at <http://flaeohist/database/Reference/synthesis>. Relationship of clusters to samples can be seen in Text-figure 14 and Table 5 indicates which species are responsible for the clusters seen.

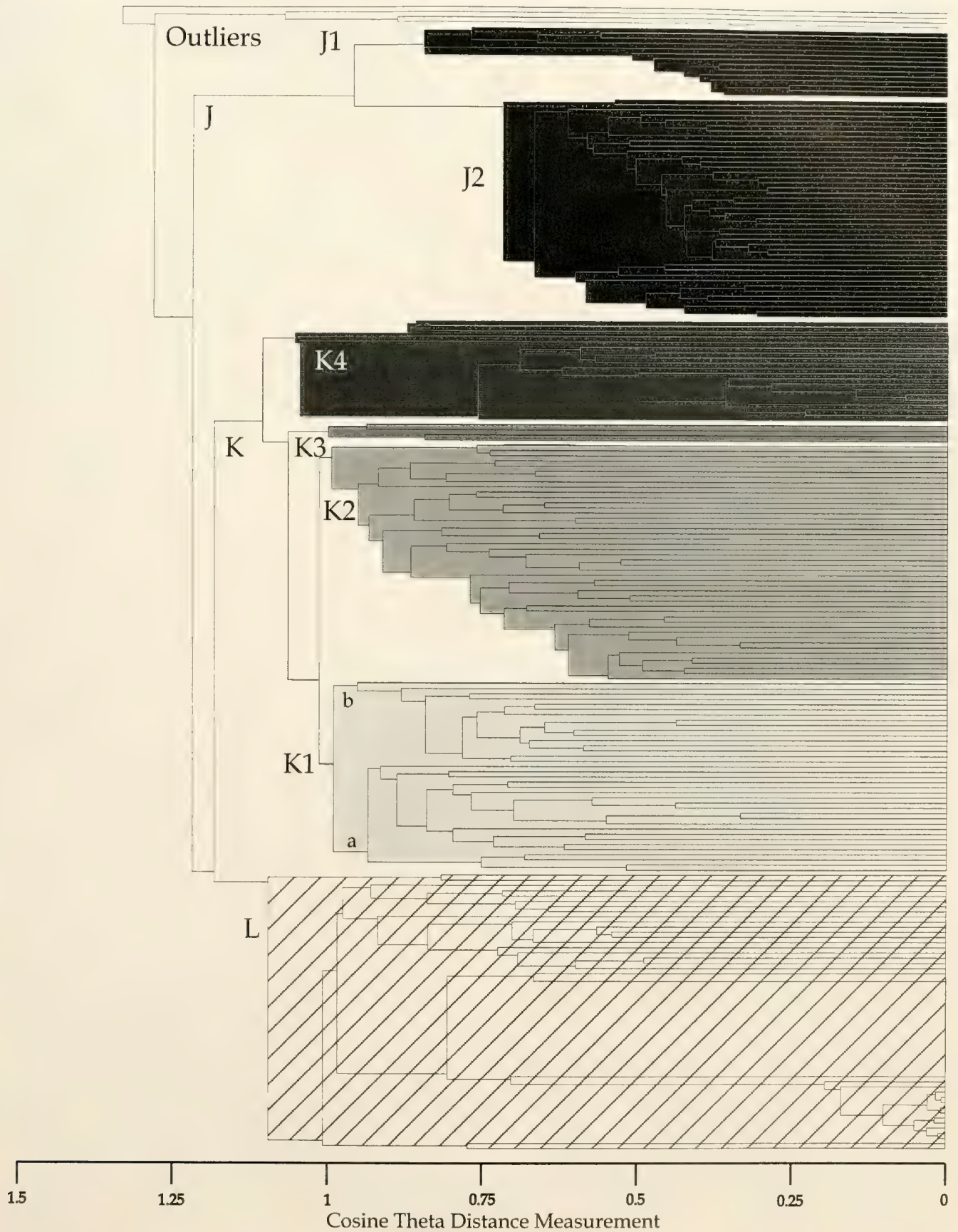


Table 5.—Occurrence (O), constancy (C), and fidelity (F) values for each taxon in each cluster from the compiled data (core, push core, and vegetation samples) cluster analysis. Taxa are sorted in R-mode dendrogram order. Class designation: P = Pelecypoda, G = Gastropoda.

R-mode Cluster	Class	Faunal Group	Q-mode Cluster								
			J			K			L		
			O	C	F	O	C	F	O	C	F
XIa	G	<i>Bittium varium</i> (Pfeiffer)	56	92	51	88	82.2	45.3	4	7.4	4.1
	G	<i>Cerithium muscarum</i> Say juv.	50	82	52	70	65.4	41.8	5	9.3	5.9
	P	<i>Brachidontes exustus</i> (Linnaeus)	45	74	36	105	98.1	47.4	19	35.2	17.0
	G	<i>Crepidula</i> spp.	37	61	47	73	68	53	—	—	—
	G	<i>Modulus modiolus</i> (Linnaeus)	18	30	30	68	64	64	3	6	6
	P	<i>Pteria longisquamosa</i> (Dunker)	9	15	18	67	62.6	77.2	2	3.7	4.6
	P	<i>Laevicardium mortoni</i> (Conrad)	45	74	50	60	56	38	10	19	12
	P	<i>Tellina</i> spp.	47	77	63	46	43	35	1	1.9	1.5
	P	<i>Transennella</i> sp.	48	79	31	78	73	29	54	100.0	39.7
	G	<i>Cerithium muscarum</i> Say	13	21	22	54	50	53	13	24.1	25.1
	P	<i>Chione cancellata</i> (Linnaeus)	4	7	7	71	66	76	8	14.8	16.9
	G	<i>Olivella pusilla</i> (Marrat)	5	8	13	40	37	58	10	18.5	28.9
XIb	G	Marginellid	11	18.0	26.7	43	40	60	5	9.3	13.7
	G	<i>Bulla striata</i> Bruguière	32	52.5	53.4	39	36.4	37.1	5	9.3	9.4
	P	<i>Cumingia tellinoides</i> (Conrad)	10	16	27	40	37	61	4	7.4	12.1
	P	<i>Parastarte triquetra</i> (Conrad)	16	26	34	18	17	22	19	35.2	45.0
XIc	P	<i>Mytilopsis leucophaeata</i> (Conrad)	27	44	98	1	0.9	2.1	—	—	—
	P	Mytilid	32	52	100	—	—	—	—	—	—
	P	<i>Semele proficua</i> (Pulteney)	40	65.6	100.0	—	—	—	—	—	—
	P	<i>Polymesoda maritima</i> (d'Orbigny)	51	84	98	2	2	2	—	—	—
	G	Hydrobiidae	52	85.2	92.9	7	6.5	7.1	—	—	—
	G	<i>Cerithidea</i> spp.	52	85.2	85.1	12	11.2	11.2	2	3.7	3.7
	P	<i>Anomalocardia auberiana</i> (d'Orbigny)	57	93.4	65.4	39	36	26	7	13.0	9.1
	G	<i>Acteocina canaliculata</i> (Say)	57	93.4	69.0	35	33	24	5	9.3	6.8
XIIa	G	<i>Rictaxis punctostriatus</i> (C.B. Adams)	3	5	64	3	3	36	—	—	—
	G	<i>Alys</i> sp.	—	—	—	1	0.9	100.0	—	—	—
	G	<i>Cerodrillia</i> sp.	—	—	—	1	1	100	—	—	—
	G	<i>Lymnaea columella</i> Say	1	2	100	—	—	—	—	—	—
	G	<i>Nassarius</i> sp.	2	3	100	—	—	—	—	—	—
	G	<i>Assininea succinea</i> (Pfeiffer)	1	2	100	—	—	—	—	—	—
	G	<i>Busycotypus</i> sp.	1	2	100	—	—	—	—	—	—
	G	<i>Melampus coffeus</i> (Linnaeus)	3	5	100	—	—	—	—	—	—
	G	Turridae sp. A	—	—	—	2	2	100	—	—	—
	G	<i>Haminoea</i> sp.	—	—	—	1	1	100	—	—	—
	G	<i>Epitonium rupicola</i> (Kurtz)	—	—	—	2	1.9	100.0	—	—	—
	G	Polygyridae	5	8	100	—	—	—	—	—	—
	G	Physidae	3	5	100	—	—	—	—	—	—
	G	Naticidae	—	—	—	1	1	100	—	—	—
	P	<i>Parvilucina multilineata</i> (Tuomey & Holmes)	1	2	23	6	5.6	77.4	—	—	—
	P	<i>Luciniscia nassula</i> (Conrad)	—	—	—	3	2.8	100.0	—	—	—
	G	<i>Fasciolaria</i> spp.	—	—	—	1	0.9	100.0	—	—	—
	P	<i>Semele bellastrata</i> (Conrad)	—	—	—	2	2	50	1	1.9	49.8
	P	<i>Lucina</i> sp.	2	3	100	—	—	—	—	—	—
	P	<i>Cyrenoida floridana</i> (Dall)	5	8	81	2	1.9	18.6	—	—	—
	G	<i>Diodora</i> sp.	—	—	—	2	2	100	—	—	—
	P	<i>Ostrea equestris</i> Say	3	5	84	1	1	16	—	—	—
	G	<i>Eulithidium</i> sp.	—	—	—	2	1.9	100.0	—	—	—
	G	<i>Gastrocopta</i> sp.	7	11	100	—	—	—	—	—	—
	G	<i>Marshallora nigrocincta</i> (C.B. Adams)	1	2	20	7	7	80	—	—	—
	G	<i>Hyalina</i> sp.	—	—	—	1	0.9	33.5	1	1.9	66.5
	P	<i>Codakia</i> spp.	—	—	—	9	8.4	100.0	—	—	—

Table 5.—Continued.

R-mode Cluster	Class	Faunal Group	Q-mode Cluster								
			J			K			L		
			O	C	F	O	C	F	O	C	F
	P	<i>Anodonta alba</i> ? Link	—	—	—	1	1	100	—	—	—
	G	<i>Lithopoma americanum</i> (Gmelin)	—	—	—	4	4	100	—	—	—
	G	Eulimidae	—	—	—	3	2.8	100.0	—	—	—
	P	<i>Lucina pectinata</i> (Gmelin)	4	7	100	—	—	—	—	—	—
	G	<i>Turbonilla</i> spp.	3	5	51	5	5	49	—	—	—
	G	<i>Melongena corona</i> (Gmelin)	6	10	68	5	4.7	32.2	—	—	—
	G	<i>Caecum cornucopiae</i> (Carpenter)	1	2	23	4	4	52	1	1.9	25.6
	G	<i>Cerithiopsis</i> spp.	3	5	37	9	8.4	63.1	—	—	—
	G	<i>Crassispira</i> spp.	—	—	—	9	8	82	1	1.9	18.0
	P	<i>Nucula proxima</i> Say	—	—	—	7	6.5	77.9	1	1.9	22.1
	G	<i>Rissoina cancellata</i> Philippi	2	3	21	13	12	79	—	—	—
	G	<i>Batillaria minima</i> (Gmelin)	9	15	84	3	3	16	—	—	—
	P	<i>Mysella planulata</i> (Stimpson)	1	2	14	9	8.4	70.7	1	1.9	15.6
	G	<i>Amara retifera</i> (Dall)	1	2	10	16	15.0	90.1	—	—	—
	G	Muricidae sp. B	11	18	76	6	6	24	—	—	—
	G	<i>Olivella</i> ? sp.	—	—	—	5	4.7	71.6	1	1.9	28.4
	G	Muricidae sp. A	3	5	32	9	8.4	55.4	1	1.9	12.2
	G	<i>Finella</i> sp.	—	—	—	6	6	75	1	1.9	24.8
	G	Conidae juv.	1	2	23	6	5.6	77.4	—	—	—
	G	Pyramidellidae	6	10	47	8	7	36	2	3.7	17.6
	P	<i>Argopecten irradians</i> (Lamarck)	1	2	14	7	6.5	55.0	2	3.7	31.2
	P	<i>Tagelus</i> sp.	16	26	100	—	—	—	—	—	—
	P	<i>Pitar simpsoni</i> (Dall)	2	3	13	11	10.3	41.7	6	11.1	45.0
	G	Vitrenellid	15	25	67	13	12	33	—	—	—
	G	<i>Cyclostremiscus suppressus</i> (Dall)	5	8	32	19	18	68	—	—	—
	P	<i>Limaria</i> sp. cf. <i>L. pellucida</i> (C.B. Adams)	4	7	18	31	29.0	77.5	1	1.9	5.0
XIIf	P	<i>Arcopsis adamsi</i> (Dall)	7	11	34	24	22.4	66.2	—	—	—
	G	<i>Vermicularia</i> sp.	2	3	16	18	17	84	—	—	—
	G	<i>Caecum pulchellum</i> Stimpson	4	7	20	26	24	74	1	1.9	5.7
	G	Rissoiidae	2	3	8	38	35.5	91.5	—	—	—
XIIf	G	<i>Bittium varium</i> (Pfeiffer) juv.	14	23	39	38	36	61	—	—	—
	G	<i>Odostomia</i> spp.	10	16	39	27	25.2	60.6	—	—	—
	G	<i>Prunum apicinum</i> (Menke)	8	13	39	22	21	61	—	—	—
	G	<i>Schwartzella catesbyana</i> (d'Orbigny)	13	21	46	23	21.5	46.2	2	3.7	8.0
	G	<i>Truncatella</i> spp.	16	26	85	5	4.7	15.1	—	—	—
		Total number of samples/cluster		61			107			54	

(Halley, <http://sofia.usgs.gov/projects/circulation>; Johns *et al.*, 1999; NOAA NCDC website <http://www.ncdc.noaa.gov/>). In the northern and eastern portions of Florida Bay, salinity varies more than temperature at each site on both a seasonal and an annual scale. Typically at each site, there is less fluctuation in salinity from year to year in February (the “dry” season), than during July (the “wet” season). The exception is the 1998 pattern; during 1997–1998, a very strong El Niño affected regional rainfall throughout southern Florida, bringing heavy winter-time rain. This was followed by a strong La Niña

causing a hot dry summer in southern Florida. Text-figure 3 illustrates the effect of the anomalous regional wintertime rainfall on the salinity of northern and eastern Florida Bay. February 1998 resembles a typical summer pattern, whereas July 1998 resembles a winter pattern.

MODERN ANALOGUES

Five distinct molluscan associations were identified from the analysis of the modern presence-absence database. Assemblages identified by clusters B and E (Text-fig. 4) are minor components of larger commu-

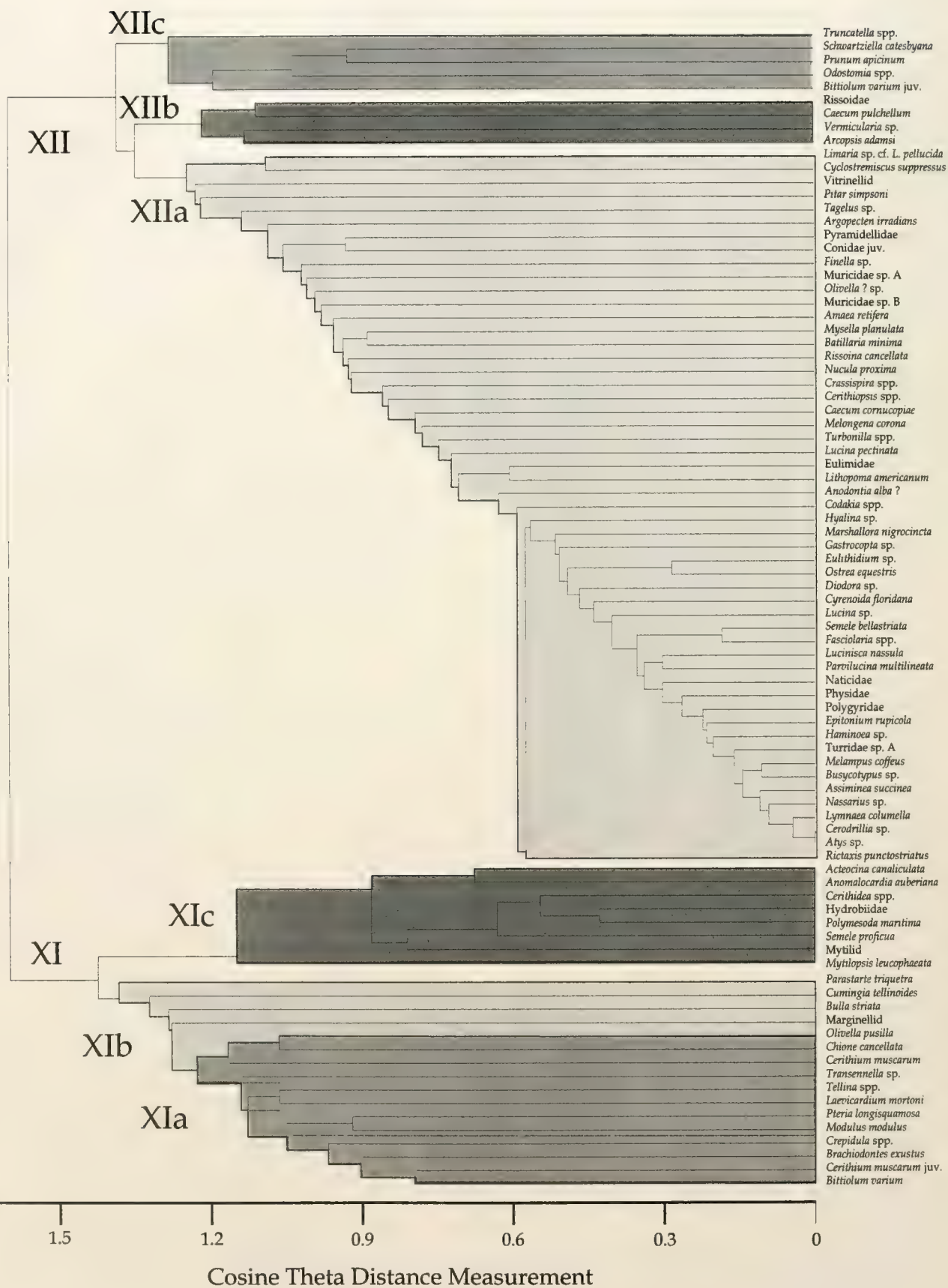


Table 6.—Salinity and temperature ranges for molluscan taxa observed at monitoring sites.

	Salinity (ppt)			Temperature (deg. C)			No. of Observations
	Minimum	Maximum	Average	Minimum	Maximum	Average	
<i>Acteocina canaliculata</i>	20.7	23.9	22.3	21.6	30.9	26.2	2
<i>Anomalocardia auberiana</i>	15.2	39.3	29.0	20.0	34.6	27.8	8
<i>Arcopsis adamsi</i>	15.8	35.1	24.8	19.2	32.0	24.8	9
<i>Argopecten irradians</i>	20.6	41.3	31.8	17.7	33.6	27.6	22
<i>Batillaria minima</i>	16.7	41.0	27.5	19.4	34.6	26.6	24
<i>Bititolum varium</i>	13.0	41.3	27.6	19.9	34.6	26.2	26
<i>Brachiodontes exustus</i>	10.2	41.3	27.4	19.2	34.6	27.4	85
<i>Bulla striata</i>	19.6	40.5	28.8	16.5	33.4	27.9	12
<i>Busycotypus</i> spp.	31.9	36.9	34.7	23.9	33.3	29.1	3
<i>Caecum pulchellum</i>	15.2	28.2	22.4	20.0	32.0	27.6	3
<i>Carditamera floridana</i>	17.1	39.7	31.7	21.4	34.2	28.2	10
Cerithid	10.2	33.3	23.2	17.7	33.4	26.9	12
<i>Cerithium muscarum</i>	17.1	40.5	29.8	19.9	34.6	28.6	10
<i>Cerithium</i> spp.	15.8	38.4	30.9	21.0	34.6	28.8	21
<i>Chione cancellata</i>	24.4	41.3	34.1	25.5	34.2	30.4	18
<i>Columbella</i> spp.	17.6	40.0	34.3	21.5	34.2	29.0	18
<i>Crepidula</i> spp.	15.4	40.5	29.7	19.4	34.6	26.3	43
<i>Diodora</i> sp.	20.6	37.0	30.0	20.7	34.6	28.5	9
<i>Fasciolaria</i> spp.	21.8	39.7	31.4	17.4	34.2	27.1	19
<i>Laevicardium mortoni</i>	12.7	41.0	28.3	19.4	34.6	26.6	12
<i>Limaria</i> sp. cf. <i>L. pellucida</i>	27.0	36.9	30.9	20.2	32.0	27.0	4
<i>Lithopoma americanum</i>	29.0	36.8	33.4	21.5	32.3	28.1	5
<i>Lucina pectinata</i>	12.7	25.1	18.9	23.8	28.8	26.3	2
Marginellid	12.7	36.5	24.4	17.4	32.9	25.3	15
<i>Melampus coffeus</i>	21.3	34.4	27.9	32.3	32.9	32.6	2
<i>Melongena corona</i>	14.1	41.0	24.9	19.8	33.0	25.8	16
<i>Modulus modulus</i>	19.6	39.7	30.7	17.6	34.6	28.4	21
Muricidae sp.	26.9	36.8	31.5	20.0	30.4	25.9	5
<i>Ostrea equestris</i>	2.7	39.0	20.5	19.2	31.3	24.8	15
<i>Parastarte triquetra</i>	20.7	40.5	31.6	21.6	34.6	30.1	4
Pinnidae	27.0	38.4	33.6	20.2	32.1	27.9	6
<i>Pleuroploca gigantea</i>	31.9	34.3	33.1	23.9	31.0	27.5	2
<i>Prunum</i> sp.	17.1	41.0	30.4	16.5	34.6	28.3	25
<i>Pteria longisquamosa</i>	10.2	40.5	29.3	17.4	33.4	27.2	62
<i>Tegula fasciata</i>	29.0	38.4	34.6	21.5	31.9	27.3	7
Tellinid	12.7	40.5	27.6	24.0	32.1	29.2	4
<i>Transennella</i> sp.	15.2	39.3	28.4	20.0	34.6	28.3	7
<i>Truncatella</i> spp.	15.2	30.5	22.2	20.0	30.9	23.2	4
<i>Turbo castanea</i>	21.3	38.4	33.2	17.6	32.9	26.4	16
<i>Turridae</i> sp. A	20.7	28.2	24.4	21.6	32.0	26.8	2

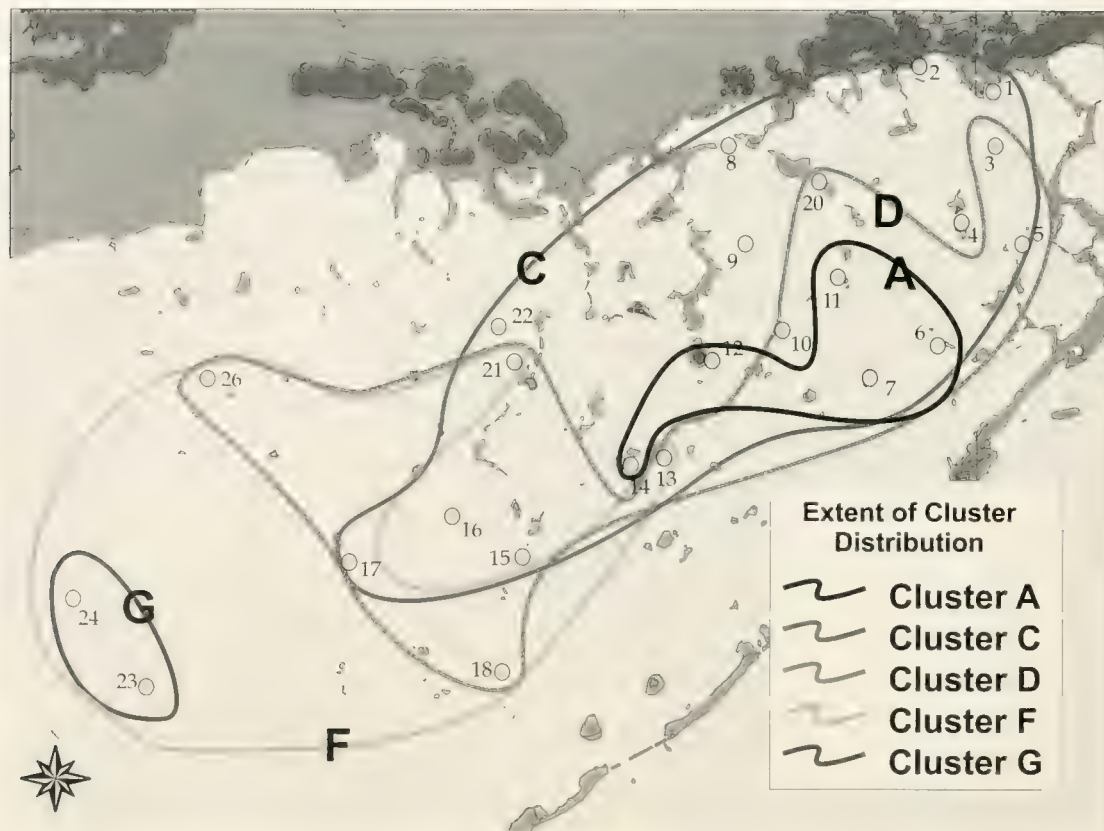
nities within Florida Bay, and are not considered significant for this study. Text-figure 13 shows the geographic range of five communities in Florida Bay, and Text-figure 3 shows the changing distribution from season to season over the period of observation.

Batillaria/Melongena Assemblage

The *Batillaria/Melongena* assemblage defined by cluster A represents a unique set of environmental con-

ditions. This assemblage frequently co-occurs with the *Brachidontes* assemblage (cluster C), but occupies a unique subenvironment at each site. Subenvironments were not analyzed separately, therefore, the occurrence of the *Batillaria/Melongena* assemblage is not always reflected on the distribution maps (Text-fig. 3). This assemblage appears to be restricted to eastern and central Florida Bay, in very shallow areas with sparse sub-aquatic vegetation and in close proximity to islands.

Text-figure 12.—R-mode cluster of compiled data (cores, push-cores, and vegetation samples). Clusters were generated using MVSP statistical package (Kovach Computing Services, MVSP Plus, version 3.1) on log-ratio transformed and centered percent abundance data, using unweighted paired group method, average-linkage (UPGMA), with cosine theta distance measurement, dual clustering procedure, and random input order. Full data matrix sorted in dendrogram order can be viewed at <http://flaeohist/database/Reference/synthesis>.



Text-figure 13.—Map showing range of distribution of presence-absence clusters over course of sampling period from February 1996 through July 1999. This represents a compilation of data shown on individual seasonal plots in Text-figure 3. Clusters B and E are not shown; the distributions are limited and non-contiguous.

Dense *Batillaria minima* consistently have been present at site 14 since the beginning of our observation period (Text-fig. 3). Salinity does not appear to be a strong controlling factor; *Batillaria minima* and *Melongena corona* have been found from mesohaline to hypersaline conditions (Table 6). These observations are in general agreement with Turney and Perkins (1972).⁵ They identify *Melongena corona* as a common species in the northern subenvironment and *Batillaria minima* as an intertidal species found in sediments near land; we have commonly found *Melongena corona* in the northern transitional and eastern divisions of Florida Bay.

⁵ Turney and Perkins (1972) indicate it is unusual to find *Batillaria* anywhere but in the immediate vicinity of dry land, and they place a great deal of significance on finding it "more than 1/4 mile from present land" at site 7403. Site 7403 is in close proximity to our site 11, on the southern end of the mud bank extending south from Park Key. We have observed live *Batillaria* at site 11, and on other mudbanks extending outward from land (sites 4, 7, 12). We believe this is a typical habitat for *Batillaria* and disagree with Turney and Perkins' interpretation of its presence as being indicative of recent migration of Park Key (Turney and Perkins, 1972, p. 29).

Brachidontes Assemblage

The *Brachidontes* assemblage defined by cluster C is the most predominant molluscan community found in eastern and central Florida Bay. *Brachidontes exustus* is commonly found alive at most sites in this region of the bay, regardless of salinity, water depth, substrate, or clarity. The low fidelity values for *Brachidontes exustus* in cluster C (Table 4) are due to the ubiquitous nature of the species. Although *Brachidontes exustus* is euryhaline, ranging from 10.2–41.3 ppt, the average value is 27 ppt.⁶ *Brachidontes exustus* have been found in the deepest parts of the basins in eastern Florida Bay, bysally attached to exposed limestone, and on the tops of mud banks attached to sub-aquatic vegetation. *Brachidontes exustus* are found attached to almost all common types of vegetation, including *Thalassia*, *Halodule*, *Sargassum*, *Chondria*,

⁶ The mean and median salinity values for *Brachidontes* are 27.45 and 28.8 ppt, based on 85 observed occurrences of the species. These values do not take into account the abundance of the species at a site, and may in part reflect the frequency of sampling within higher salinity ranges (see Text-fig. 2).

and *Laurencia*, and to exposed limestone and shell debris. When *Brachidontes exustus* are very abundant they commonly form "nests" in clumps of *Chondria*, *Laurencia*, and dead *Thalassia*, and they were observed forming a dense "*Brachidontes*-mat" by attaching to each other across the top of an expansive shoaling area (2/97, site 12). The most abundant *Brachidontes exustus* concentrations we have observed are typically found on the sides of the mud banks in clumps of *Chondria* and/or *Laurencia* in relatively murky water. In the process of collecting and processing samples, we have determined that *Brachidontes exustus* are very tolerant of low water quality; they have been found alive several days after collection in sealed plastic bags, filled with decaying organic material. Given the wide range of environmental conditions under which *Brachidontes exustus* have been found, it is difficult to determine what factors control their distribution. Given these tolerances it is noteworthy that *Brachidontes exustus* are primarily restricted to the northern transitional, eastern, and central portions of Florida Bay. A possible explanation is that their distribution is a function of decreased competition or fewer predators in this region of the bay.

An examination of the associated species that separate the sub-clusters within C indicates some of the environmental variables that control the distribution of the *Brachidontes* assemblages. Sub-cluster C1 is defined by the co-occurrence of *Brachidontes exustus* with *Prunum apicinum*; these species are most commonly found together on clumps of *Laurencia* or *Chondria*. The co-occurrence of *Brachidontes exustus* and *Pteria longisquamosa* with *Argopecten irradians* or *Chione cancellata* delimits sub-cluster C2. This group of species is indicative of relatively clear water and abundant healthy *Thalassia*; macro-benthic algae may be present. Sites with *Brachidontes exustus* alone or with *Batillaria minima* form sub-cluster C3. *Batillaria minima* are present when the water is very shallow, the substrate is generally soft mud, and the vegetation is sparse. Due to *Brachidontes exustus* tolerance of varying salinity and substrate conditions and relatively poor water quality, the presence of *B. exustus* alone may indicate the environment is not suitable for other epifaunal molluscs. Sub-clusters C4 and C5 have relatively high values for faunal richness. *Pteria longisquamosa*, *Crepidula* spp., *Bittium varium*, and *Prunum apicinum* may be present with *Brachidontes exustus*, and a number of other species in R-mode cluster Ia. Species from R-mode cluster Ib are included in sub-cluster C5. These diverse faunas are typically present when the substrate consists of mixtures of *Thalassia* and macro-benthic algae including *Polysiphonia*, *Chondria*, and *Laurencia*. Sub-clus-

ter C6 is defined by the presence of *Brachidontes exustus* and *Crepidula* spp.; *Crepidula* are generally found on *Thalassia*, and like *Brachidontes exustus*, appear to be relatively tolerant of reduced water quality.

Count-data from the modern vegetation samples and the push cores are in agreement with presence-absence observation data, and provide further evidence of the predominance of *Brachidontes exustus* in the molluscan fauna of Florida Bay. Out of 11,597 total individuals collected on vegetation samples in July 1998, we found 5713 *Brachidontes exustus* (49.26%). These numbers are comparable to the findings of Lyons (1998). He found *Brachidontes exustus* comprised 78% of all the molluscs he collected in an extensive sampling program throughout Florida Bay in the summer of 1994 that gathered nearly 14,000 living specimens greater than 3 mm. In the pristine fraction of the push core samples, *Bittium varium* comprises 30.3% of the specimens, and *Brachidontes exustus* 13.0%, followed closely by *Transennella* sp. at 11.43%. When all the fragments and worn specimens are included from the push core data, *Brachidontes exustus* comprises 20.64% of the total molluscan specimens, and *Bittium varium* 19.74%. The lower values for *Brachidontes* in the pristine sub-set are probably due to the fragility of the shell.

Pteria Assemblage

Pteria longisquamosa [= *Pinctada radiata* Turney and Perkins] and its associated species *Modulus modiolus*, and *Argopecten irradians* define cluster D. This association of species is typically found on the sides of mudbanks (40–150 cm of water) in dense *Thalassia* beds, relatively clear water, and salinities between 20 and 40 ppt⁷ (Table 6), in eastern, central, western and Atlantic transition zones of Florida Bay. Although *Pteria longisquamosa* has been found at its densest concentrations attached to *Thalassia*, it has also been found on macro-benthic algae, particularly *Chondria* and *Laurencia*, and it has the ability to camouflage itself to match the color of the vegetation to which it attaches. The occurrence of *Pteria longisquamosa* in relatively clear water raises an interesting question of whether *P. longisquamosa* occurs there because the water is clear, or whether the water is clear due to the filtering activity of *P. longisquamosa*. The latter especially may be true where *Pteria longisquamosa* are extremely abundant. *Pteria longisquamosa*, however, seem unable to survive in water of diminished quality;

⁷ The mean and median salinity values for *Pteria longisquamosa* are 29.3 and 29.7 ppt, based on 62 observed occurrences of the species at a site. These values do not take into account the abundance of the species at a site, and may in part reflect the frequency of sampling within higher salinity ranges (see Text-fig. 2).

they generally die within hours of collection. Typically, the *Pteria* assemblage occurs outside the 20-ppt contour and to the east, south, or west of the *Brachidontes* assemblage (Text-fig. 3). Based on our observations, we believe the distribution of the *Pteria* assemblage is controlled by a combination of salinity, substrate, water depth, and water clarity.⁸ The dominance of this combination of species in a death assemblage would be indicative of polyhaline to euhaline relatively clear water, deposition on the side of a mud bank in 40–150 cm of water, and the presence of a relatively dense *Thalassia* bed.

Turney and Perkins (1972) found *Brachidontes exustus*, *Pteria longisquamosa*, *Cerithium muscarum* and *Bittium varium* to be the characteristic species of their interior subenvironment, which corresponds approximately to the eastern and central divisions of our current usage. Their results agree with our analyses. The distribution of the *Brachidontes* and *Pteria* assemblages overlap in central and eastern Florida Bay (Text-fig. 13). Turney and Perkins (1972, p. 10) state that the molluscs in the interior subenvironment are able to “survive large salinity fluctuations and other effects of poor circulation.” They point out the ability of the characteristic species to survive in other subenvironments, but suggest that one reason they flourish in the interior may be a lack of competition. Our data support the idea of wide salinity tolerances for these assemblages, but our data indicate *Pteria longisquamosa* is sensitive to water quality. This apparent discrepancy can be explained by the fact that Turney and Perkins were analyzing death assemblages.

The “Western” Assemblages

The *Turbo*, *Tegula*, and *Columbella* association that forms cluster F1 has been found at three sites (17, 18, 23) in the western, Atlantic and Gulf transition zones; these sites have a mixture of various types of sub-aquatic vegetation including *Thalassia*, *Syringodium* and *Halodule* and calcareous green algae. These sites also have varying substrates and water depths, because each site has a channel bordered by a mudbank or sandbar. Currents flowing through the channels can be strong at times, and the water is typically clear; salinities have ranged from 25–38 ppt. Based on our observations, we consider this assemblage to be indicative of near normal marine conditions (upper polyhaline to euhaline), relatively clear water, and the presence of sub-aquatic vegetation. Currents and varying substrates also may be determining factors in the dis-

tribution of the F1 assemblage, but we have not observed this assemblage frequently enough to reach a conclusion.

Cluster F2 is a weak association of species including *Cerithium* spp., *Chione cancellata*, *Carditamera floridana*, and *Columbella* spp. and other faunal groups from R-mode cluster Ia. The cluster is formed of samples from sites 13, 17, 21, 24, and 26 in the central, western and Gulf transition zones of Florida Bay. Salinities for the sites in cluster F2 range from 30–39. Our data suggest this assemblage represents euhaline conditions, but the limited observations and weak association of fauna make this a speculative conclusion.

Pinnidae and *Pleuroploca gigantea* are the critical fauna in cluster G. These taxa are generally found in the western most sites (23 and 24) in the Gulf transition zone and they are representative of open marine euhaline conditions. Pinnidae are found in shallow shoaling areas on top of banks, partially submerged in the substrate. The substrates have varied from muddy calcareous sand to firm calcareous mud. These fauna have been rarely observed, but seem indicative of euhaline conditions.

Our observations of the more euhaline marine assemblages differ from Turney and Perkins (1972). *Lithopoma americanum* [= *Astraea americana* Turney and Perkins, 1972] and *Tegula fasciata* were listed as characteristic species of Turney and Perkins's (1972, p. 13) Atlantic subenvironment, and they stated that “the Atlantic group is composed of species which are almost entirely restricted to that part of the bay which is influenced by the Atlantic Ocean.” Although our observations of living *Lithopoma americanum* and *Tegula fasciata* are limited, we have observed both species in the central (site 17), Atlantic (site 18), and Gulf transition (site 23) zones.

Comparison of Presence-Absence Data with Other Data

Through quantitative and qualitative comparisons of the death assemblages represented by the push core data with other data sets (Lyons, 1995, 1998; Turney and Perkins, 1972; and our modern vegetation and observation data discussed above) we have determined that the push core data are a valid representation of the fauna that have lived at each site during the 0–10 years preceding collection. The prominence of *Brachidontes exustus* and *Bittium varium* in the push cores from sites 8, 12, 13, and 20 agrees with our modern vegetation data from those sites. *Transennella* sp. and other infaunal organisms (absent in the presence-absence observation data and the vegetation sample data) are a significant component of the push-core assemblages. Their absence from the observation and veg-

⁸ Water depth, water clarity, and vegetation are not independent of each other. The tops of the mudbanks typically have less vegetation and more material in suspension than the sides of the banks.

etation data sets does not indicate a lack of agreement with the push core data but is simply an artifact of our method of observing and sampling (see discussion under methods). Turney and Perkins (1972) did a detailed analysis of the death assemblages at over 75 stations in Florida Bay in the 1950's and they concluded that "transportation of shells larger than silt size is not significant in Florida Bay" (1972, p. 32). Only local migration of shells takes place and "faunal dislocations" are rare. Diagenetic and depositional processes have little effect on the distribution of molluscan assemblages (Turney and Perkins, 1972, p. 35). Thus, their work supports our conclusion that push core data provide a valuable addition for down-core comparison to the historical data set.

HISTORICAL PISTON CORE DATA

Three primary clusters are formed by the analysis of the compiled data set (modern vegetation samples, push cores, and piston cores) (Text-fig. 11). Only the *Brachidontes* assemblage that defines cluster C in the modern analysis is represented in the compiled data set as cluster K. The other modern assemblages identified in the cluster analysis of the presence-absence data set are not represented in the piston core data.

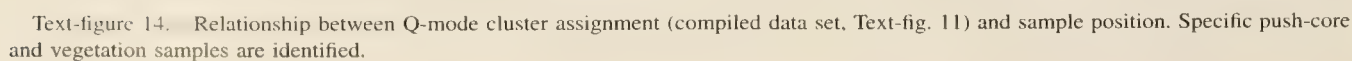
The absence of the modern assemblages (with the exception of the *Brachidontes* assemblage) from the piston cores can be explained by a number of factors. The *Batillaria/Melongena* assemblage typically is limited to shallow-shoaling areas in relatively close proximity to land. The four piston cores were not taken under these conditions in the modern environment, and the nearly complete absence of *Batillaria minima* and *Melongena corona* from the piston cores implies these conditions did not exist in the past at the localities where piston cores were taken. Clusters B and E, the *Ostrea/Arcopsis* assemblage and the *Laevicardium* assemblage, are limited to only a few sites in the modern sampling, are loosely associated groups, and are generally affiliated with *Brachidontes*. When these species are present within the piston core, the samples join with other clusters. *Pteria longisquamosa* are present in the piston cores (primarily RB19B and PK37), but do not form the discrete *Pteria* assemblage seen in cluster D of the modern analysis. Instead, *Pteria longisquamosa* are a component of the *Brachidontes* assemblage in cluster K1a. The fragility and low preservation potential of *Pteria longisquamosa* shells most likely affect their relative abundance in the piston core data, although they are easily recognizable from small fragments. This observation agrees with the results of Turney and Perkins (1972); they did not distinguish separate *Pteria longisquamosa* = [*Pinctada radiata* Turney and Perkins 1972] and *Brachidontes exustus*

groups in the death assemblages from the interior sub-environment where they found both species to be abundant.

The key species in the two western assemblages (clusters F and G) are completely missing from the piston cores. *Turbo castanea*, *Tegula fasciata* and *Columbella* spp., which comprise cluster F1, are not present in any piston core samples. Cluster F2 is a more loosely associated group, defined by the presence of *Columbella* spp., *Cerithium* spp., *Chione cancellata*, and *Carditamera floridana*; *Carditamera* and *Columbella* are absent from all piston core samples. *Cerithium* and *Chione* are present, but typically in association with *Brachidontes* or *Transennella* dominated assemblages. Pinnidae and *Pleuroploca gigantea* (cluster G) are absent from the piston cores, but *Lithopoma americanum* is a rare component in the upper 50 cm of piston core BA6A. The absence of the *Turbo/Tegula/Columbella* and Pinnidae/*Pleuroploca* assemblages from the piston cores indicates that during historical times conditions in northern, eastern and central Florida Bay did not reach the more open marine conditions currently seen in the western, Gulf, and Atlantic transition zones.

Compiled Data

The down-core distribution of the three primary clusters formed by the compiled data analysis, and the relationship of the modern vegetation and push core data to the historical piston core data, are shown in Text-figure 14. The unique character of the molluscan assemblage in Little Madeira Bay (site 8 and piston core T24 site) is apparent. Cluster J (Text-fig. 11) is predominantly composed of samples from piston core T24 and modern site 8. Abundant Hydrobiidae and *Anomalocardia auberiana*, combined with the less common *Acteocina canaliculata*, *Polymesoda maritima*, and *Cerithidea* spp. (R-mode XIc group, Text-fig. 12), separate these samples from the samples in eastern and central Florida Bay. The species in R-mode cluster XIc are relatively rare outside of Little Madeira Bay. Only a few samples from other localities join cluster J (piston core PK37 10 cm; push cores from site 20, and a push core and vegetation sample from site 12); these samples join the cluster due to the presence of *Anomalocardia* and *Acteocina*. Turney and Perkins (1972) identified *Anomalocardia auberiana* [= *Anomalocardia cuniemeris* Turney and Perkins, 1972] as the characteristic species of the northern transitional zone, and *Acteocina canaliculata* [= *Retusa canaliculata* Turney and Perkins, 1972] as a common species. Lyons (1996, 1999) has determined that zones of *Anomalocardia* occurrence will shift with changes in salinity. Thus, the higher abundance of *Anomalocardia*





Text-figure 15.—“Blow-out” areas at Bob Allen mudbank, February 1999. Sharp transition between lush *Thalassia* beds and areas of gelatinous calcareous mud are visible. Photo courtesy of Thomas Scott, Florida Geological Survey.

and *Acteocina* in some samples from Pass Key and Russell Bank may be indicative of lowered salinities.

Samples from piston cores RB19B and PK37, and the upper portion of BA6A, are primarily grouped in cluster K (Text-figs. 11 and 14). This is equivalent to the *Brachidontes* assemblage identified in the modern presence-absence data analysis. Modern push cores and vegetation samples from the corresponding sites (12, 13, and 20) also fall into cluster K in the combined analysis. These sites occur within eastern and east-central Florida Bay, and they can be characterized as shallow mud banks with sub-aquatic vegetation and macro-benthic algae present. Salinities have ranged from 17–33 ppt at site 20, 19–37 ppt at site 12 and 27–41 ppt at site 13 during our periods of observation. Typically, either the *Brachidontes* or *Pteria longisquamosa* assemblages have dominated at these sites in the modern presence-absence data (Text-fig. 3). The prevalence of the *Brachidontes* assemblage down-core for PK37 and RB19B, and down to approximately 54cm in BA6A, indicates that the general environmental conditions were the same in the past. The common species in cluster K correspond to the characteristic species identified by Turney and Perkins (1972) for their interior subenvironment.

Samples from the lower portion of piston core

BA6A are dominated by the *Transennella* assemblage that defines cluster L. This assemblage also is seen in portions of RB19B (30 cm and 118 cm) and PK37 (6 cm). This is an infaunal assemblage and so it was not identified in the modern presence-absence analysis. *Transennella* sp. are present in the modern push core samples, but they are components of diverse *Brachidontes* assemblages, and thus the samples join cluster K. Bob Allen mudbank today (site 13) is distinctive among the sites discussed here. Lush *Thalassia* beds adjoin “blow out” areas at site 13 (Text-fig. 15) and the transition from grass to gelatinous carbonate mud is very sharp. Low diversity *Transennella* assemblages seen in the piston core may be the down-core representation of these modern “blow-out” areas, but we have not sampled the modern analogue for this cluster and can only speculate on what it indicates about the environmental conditions.

Piston Core T24

Historical changes in molluscan fauna at the mouth of Taylor Creek (piston core T24) are shown in Text-figure 7. The gradual decrease of the R-mode X1c and the increase in *Brachidontes exustus*, *Crepidula* spp., and *Cerithium muscarum* up-core illustrate the gradual increase in salinity that has occurred at this site during

the time of deposition. *Brachidontes exustus* increase significantly in the upper 20 cm of the core. Modern analogue data (discussed herein; Turney and Perkins, 1972; Lyons, 1996, 1998, 1999) have demonstrated that *Brachidontes exustus* seem most abundant in areas of fluctuating salinity and in areas where macro-benthic algae are available for habitation. Fluctuations in salinity at this site could be attributed to changes in fresh-water flow due to climatic change, or changes in water management practices, or it could be due to long-term changes in sea level. Fluctuations in the relative abundance of Hydrobiidae may be directly indicative of changes in fresh water flow. Hydrobiidae are minute (generally less than 3 mm) fresh-water gastropods that cannot survive in estuarine waters. They arrive in Little Madeira Bay via terrestrial freshwater flow through Taylor Creek, and perhaps their abundance can be related to flow rates, but additional field-testing is necessary. Despite the obvious changes in the relative abundance of individual species, the entire piston core falls within cluster J and *Anomalocardia auberiana*, Turney and Perkins' (1972) indicator of the northern subenvironment, is present throughout the piston core. In addition, diversity, evenness, faunal richness, and number of individuals remain relatively constant compared to the other piston cores.

Piston Core PK37

Deposition at Pass Key (piston core PK37) (Text-fig. 8) has been relatively rapid, and the piston core represents only the latter half of this century. *Brachidontes exustus* has dominated the assemblage at this site during the period of deposition, and below 26 cm, the relative abundance of *B. exustus* is fairly constant. Above 26 cm, however, a great deal of fluctuation occurs. Seemingly dramatic changes in species dominance near the top of piston core PK37 are due to extremely low numbers of individual shells and low faunal richness; which is probably a result of the rapid sedimentation rate. The complete disappearance of all species except *Brachidontes exustus* and *Transennella* sp. in the upper 6 cm may be indicative of rapid sedimentation at the site and/or conditions unfavorable to other species. The increases in *Anomalocardia auberiana* and R-mode XIc group may denote periods of decreased salinity; this assemblage is characteristic of Little Madeira Bay, and the 10 cm sample joins cluster J.

Piston Core RB19B

The piston core from Russell Bank (RB19B) (Text-fig. 9) records approximately 110 years of change at the site. The lower portion of the piston core (~1880–1922) shows fluctuations in faunal richness and numbers of individuals, but the relative abundance of the

key species does not fluctuate dramatically. *Transennella* sp. is the most abundant species in this portion of the core, but the presence of *Brachidontes exustus*, *Cerithium muscarum*, *Bittium varium* and other species in most of the samples indicates the presence of sub-aquatic vegetation. Significantly, *Anomalocardia auberiana* and other species from the R-mode XIc assemblage typical of the northern transition zone, are present before 1922. The presence of these species may indicate lower salinities and possibly the influence of a lower salinity plume. In the modern Florida Bay, a less saline plume of water is sometimes present on the western edge of the basin south of Little Madeira Bay (Text-fig. 3, July 1996; Halley, <http://sofia.usgs.gov/projects/circulation>). After 1922, significant changes occur in the relative abundance of the key fauna. *Transennella* sp. decrease, and *Brachidontes exustus*, *Bittium varium* and other components of the *Brachidontes* assemblage increase somewhat. After 1942, fluctuations become even more pronounced, until approximately 1980 when *Brachidontes exustus* increase dramatically in relative abundance, and all other key species, with the exception of *Pteria longisquamosa* and *Modulus modiolus*, decline. The increase in *Brachidontes exustus* in the upper 20 cm of the piston core corresponds to an increase in numbers of specimens (this is consistent with the findings of Lyons 1998) and a decrease in faunal richness, evenness and diversity.

Piston Core BA6A

Bob Allen mudbank (piston core BA6A) preserves a record of deposition since approximately 1784. No modern analogue has been identified for the *Transennella* sp. assemblage (cluster L) that dominates the lower portion of piston core BA6A, before 1922 (54 cm). The lowest portion of the piston core (140–158 cm) indicates either a rapidly fluctuating environment, or deposition at the transition zone between a grass bed (indicated by cluster K assemblage) and a low diversity, sparse *Transennella* sp. habitat. Beginning around 1890 to 1901, *Brachidontes exustus* becomes a significant component of the molluscan assemblage in piston core BA6A, and around 1901 the relative abundance of *Transennella* sp. declines and never again constitutes greater than 51% of the assemblage. The *Brachidontes* assemblage (cluster K), indicative of the presence of sub-aquatic vegetation) dominates the upper portion of piston core BA6A. Beginning in the late-1920's, *Lithopoma americanum*, indicative of the more euhaline western environments, is occasionally present at Bob Allen mudbank. Around 1981, *Brachidontes exustus* becomes the most dominant species in the piston core. In general, the measures of diversity

(faunal richness, evenness, and the Shannon's diversity index) all fluctuate significantly throughout the deposition of this core, and the values for numbers of individuals and faunal richness are lower in piston core BA6A, in comparison to the other piston cores examined.

SUMMARY OF SIGNIFICANT HISTORICAL FINDINGS

1) Molluscan assemblages that exist at each piston core locality today, typically existed there throughout the period of deposition represented by the piston cores. Shifts have occurred in the patterns of dominance and diversity within each piston core, but the faunal composition has not changed significantly.

2) Piston core T24, at the mouth of Taylor Creek, records gradually increasing salinity, an increase in euhaline molluscan fauna, and a decline in mesohaline molluscan fauna up core. *Anomalocardia auberiana*, typical of the northern transition zone, is present throughout the core.

3) Pass Key piston core (PK37), southeast of Little Madeira Bay, shows significant fluctuations in *Anomalocardia auberiana* and the other species indicative of the northern transition zone.

4) Between 1913 and 1933, distinctive changes occur in the molluscan assemblage at Russell Bank (piston core RB19B). *Anomalocardia auberiana*, consistently present in low percentages prior to 1922, completely disappears from the site after that time.

5) At Bob Allen mudbank (piston core BA6A) a dramatic change in faunal assemblages occurred between 1890 and 1901, from a *Transennella* sp. dominated assemblage to a *Brachidontes exustus* dominated assemblage.

6) From approximately 1930 to 1980, *Lithopoma americanum*, typical of euhaline western and Gulf transition environments, is occasionally present at Bob Allen mudbank (piston core BA6A).

7) From approximately 1930–1980 dramatic shifts in percent abundance of different species within the *Brachidontes* assemblage occur at both Bob Allen mudbank and Russell Bank.

8) Beginning around 1980, *Brachidontes exustus* becomes the dominant mollusc at Russell Bank, and faunal diversity and evenness decline. Similar increases in *Brachidontes exustus* are seen in the upper portion of all four piston cores analyzed.

CONCLUSIONS

Changes in ecosystems take place on many scales, from daily to decadal to millennial. Molluscs generally are tolerant of short-term perturbations in their environment, but they will respond to seasonal and annual changes in salinity. Thus, changes recorded in mollus-

can populations are significant. A comparison of molluscan faunal distributions in modern Florida Bay to down-core faunal distributions has revealed important details about the last 100 years of Florida Bay history.

All four cores examined show changes during the period of time represented by deposition at the individual sites, yet only the Bob Allen site recorded a complete change in molluscan assemblages. The molluscan fauna that occur throughout the cores are the same fauna that are present at those sites today. Changes that have occurred within the cores are fluctuations in patterns of dominance and diversity within a single assemblage, not complete replacement of the assemblage. For example, the *Turbo/Tegula/Columbella* assemblage indicative of more marine conditions has not existed at Bob Allen mudbank or at Russell Bank during the last 100–200 years. Nor has the northern transitional assemblage, typical of the Little Madeira Bay sites, dominated at Bob Allen or Russell Bank. Even the change that occurs around 1900 at Bob Allen mudbank does not represent complete replacement of a fauna. We have not identified a modern analogue for the *Transennella* assemblage that existed at Bob Allen prior to the turn of the century, but we do know that *Transennella* sp. occur at Bob Allen today.

The changes indicated by shifts in dominance patterns, however, do suggest the influence of some environmental factors on molluscan fauna in northern, eastern and central Florida Bay. The patterns in core T24 clearly demonstrate increasing salinity at the mouth of Taylor Creek. Freshwater outflow through Taylor Creek has been controlled by water management during the later half of this century. The change in salinity at this site may be due to water management practices, fluctuations in average annual precipitation, changes in sea level, or a combination of all of these. The record from Pass Key (core PK37) is not as clear, due in part to the rapid sedimentation rates at that site, but fluctuations in the abundance of *Anomalocardia auberiana* and other typical northern transition species at Pass Key probably reflect fluctuations in salinity. This conclusion is consistent with Lyons' findings (1996, 1998).

The age models for Russell Bank (core RB19B) and Bob Allen mudbank (core BA6A) allow us to compare changes in the molluscan fauna to historical data on human activities and rainfall (Text-figs. 9 and 10). The changes that occur between 1900 and 1910 at Bob Allen and between 1913 and 1933 at Russell indicate a shift toward less stable conditions. The disappearance of *Anomalocardia auberiana* from Russell Bank after 1922 may indicate more saline conditions. It is possible, given the increasing error in the age model with depth, or the possibility of varying sedimentation

rates with depth, that these events occurred simultaneously. During this time period, average rainfall did not fluctuate significantly in southern Florida, but substantial human alteration of the environment occurred with the construction of the Flagler Railroad in the Keys. Given the current data, it is impossible to determine if the construction contributed to changes in the molluscan fauna, but evidence indicates that the railroad restricted the natural exchange of water between the bay and the Atlantic (Swart *et al.*, 1996).

Between approximately 1930 and 1980, the molluscan fauna at Bob Allen and Russell both went through a period of fairly rapid and dramatic fluctuations. These fluctuations correspond to a period of relatively dramatic shifts in regional rainfall and to a period of significant alteration of the terrestrial environment with the construction of canals, the implementation of water management practices, and a rapidly growing population. *Lithopoma americanum*, a typically western Florida Bay euhaline species, is occasionally present at Bob Allen from approximately 1930 to 1980. The presence of *Lithopoma* may be indicative of periods of increased salinity or of fluctuating marine influence caused by the environmental perturbations.

Beginning around 1980, *Brachidontes exustus* becomes the most dominant species at Russell and Bob Allen, and it increases in dominance in the upper portion of the cores from Pass Key and Taylor. *Brachidontes exustus* is a euryhaline species that can tolerate

diminished water quality, and it is nearly ubiquitous at sites in central and eastern Florida Bay today. The concentration of this species in the upper portion of all the cores implies that salinity fluctuations have increased in the last 20 years, and/or water quality has diminished.

Additional studies of the autoecology of molluscan species will refine our knowledge of the environmental parameters that control their distribution and will increase their utility as bioindicators. We have established that the following molluscan species can serve as important biological indicators of conditions in Florida Bay during restoration: *Anomalocardia auberiana*, *Brachidontes exustus*, *Cerithidea* spp., *Pteria longisquamosa*, *Polymesoda maritima*, *Turbo castanea*, *Tegula fasciata*, and Hydrobiidae. Additional cores from eastern and central Florida Bay are being examined to geographically extend our coverage, and determine if the patterns seen here persist in other areas as well.

It is critical for effective restoration of the Florida Bay ecosystem that we understand the dynamics of the system and the degree to which physical, chemical and biological components of the system have varied in the past. Studies of modern fauna and flora provide a means to interpret biological data preserved in cores, and to determine the physical and chemical variations in the environment indicated by the biota. Once the patterns of the past are understood, we can better predict the impact of future change on the environment.

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CHAPTER 11

ECOLOGICAL CONTROLS ON BENTHIC FORAMINIFER DISTRIBUTIONS IN BISCAYNE BAY, FLORIDA

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ABSTRACT

Four benthic foraminiferal assemblages are recognized from surficial sediment samples collected in Biscayne Bay. The distribution patterns of these assemblages appear to be controlled by salinity, substrate, and organic input. Two of the assemblages are associated with open and free circulation within Biscayne Bay differentiated by affinities with Atlantic margin and Florida Bay assemblages. The third assemblage is limited to restricted environments and point-source freshwater input with oligohaline to polyhaline salinities. The fourth assemblage is associated with a region of Biscayne Bay with high phytoplankton productivity and organic input.

INTRODUCTION

The Biscayne Bay ecosystem, as an extension of the Florida Everglades, has experienced significant deterioration in environmental health as demonstrated in the disappearance of seagrass beds, decline in natural fisheries, and loss of coastal mangrove habitats over the past several decades (McIvor *et al.*, 1994). Such changes have prompted studies to investigate causal factors and the historical evolution of South Florida. In order to interpret these historical records a variety of proxies are utilized.

The utility of benthic foraminifers as environmental proxies has been demonstrated for a variety of marine environments globally (Murray, 1991). Their environmental preferences in specific ecosystems makes local studies of modern distributions particularly important for their use in historical or geological studies of a region. This paper presents the results of a study on the distribution of benthic foraminifers in surface samples collected from Biscayne Bay, and their relationship to modern environmental conditions within the Bay. These results will be utilized in the interpretation of historical records of foraminiferal assemblages from Biscayne Bay. This and future studies will provide valuable information toward the restoration of the ecosystems of South Florida.

ACKNOWLEDGMENTS

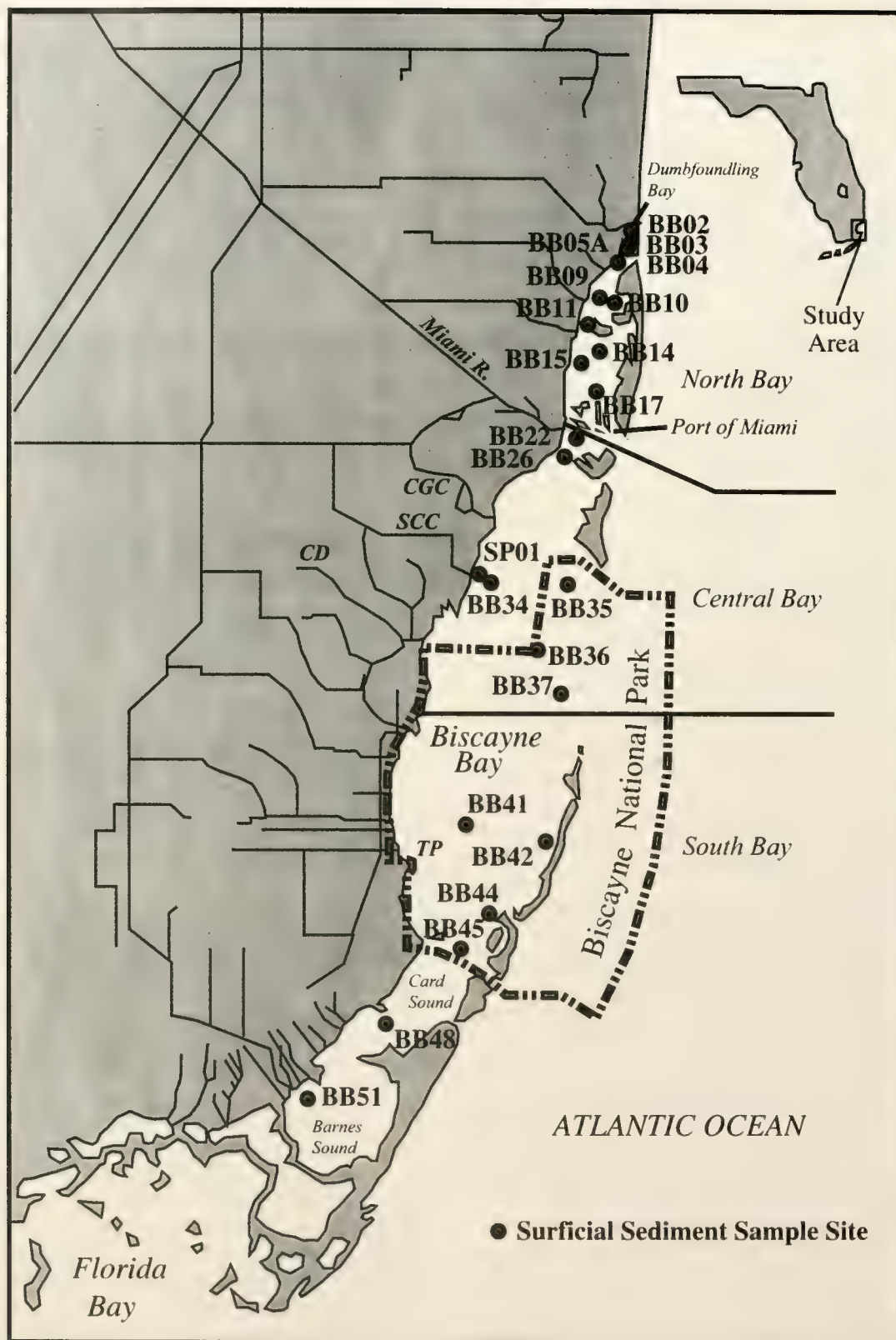
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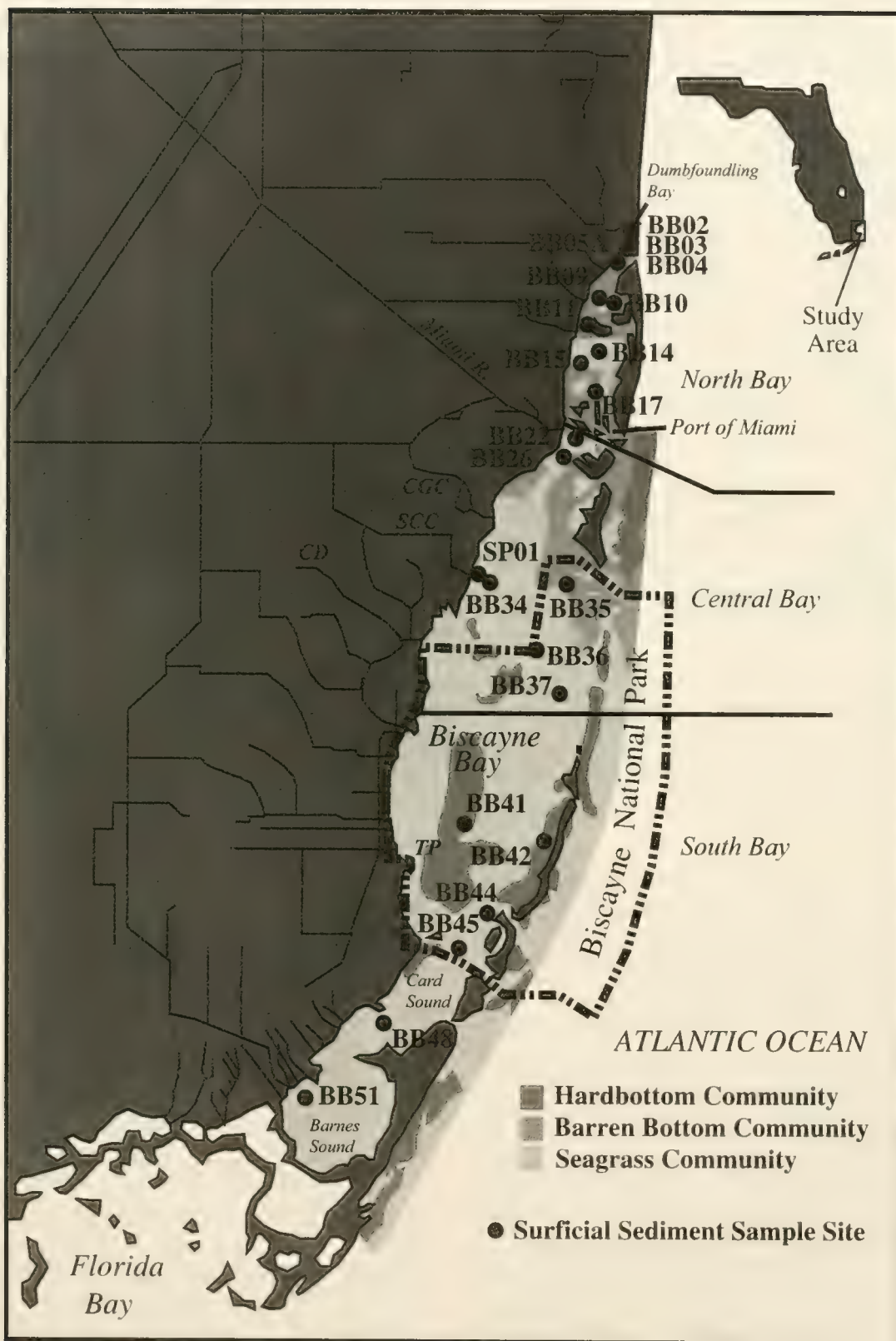
SETTING

Biscayne Bay can be divided into three regions: North, Central, and South Biscayne Bay (SFWMD, 1994) (Text-fig. 1). North Biscayne Bay is fairly restricted and extends from Dumbfoundling Bay south to, and including, the Port of Miami. The major sediment types within the northern Bay are quartz and carbonate clastic sands (Wanless, 1976) that support hard-bottom and bare-bottom benthic communities (Text-fig. 2; SFWMD, 1994). Salinities range from 31.1 to 35.2 parts per thousand (ppt) in the North Biscayne Bay with the average August salinity since 1988 being 31.20 ppt (Text-fig. 3; Table 1). The northern region of Biscayne Bay has been impacted profoundly by urbanization and development of both the coastal region and waterways. Major coastal development has increased surface and storm runoff and destroyed the natural coastal vegetation patterns. Freshwater and saltwater budgets to North Biscayne Bay were altered with the construction of causeways, canals, and inlets. Considerable dredging has destroyed benthic communities, increased turbidity (Wanless, 1976), and changed the morphology of the Bay basin.

Central Biscayne Bay represents the transition zone between the heavily impacted North Biscayne Bay and South Biscayne Bay, and includes the northern portion of Biscayne National Park. Four primary benthic communities, bare-bottom, hard-bottom, seagrass with a hard-bottom matrix, and seagrass communities (Text-



Text-figure 1.—Map of the Biscayne Bay region of South Florida including Barnes Sound and Card Sound. Solid circles indicate surface sediment sampling localities cited in the text. Canals and localities mentioned in the text include: Coral Gables Canal (CGC), Snapper Creek Canal (SCC), Cutler Drain (CD), and Turkey Point (TP).



Text-figure 2.—Map of the Biscayne Bay region of South Florida showing the distribution of major benthic communities in the Bay (modified from SFWMD, 1984).

Table 1.—Location, relative abundance (%), and diversity of benthic foraminifers and hydrologic parameters for Biscayne Bay surface samples (N/A = not available).

Sample	Latitude (degrees W)	Longitude (degrees N)	Temp (C)	Salinity (ppt)	Dis- solved Oxygen	Redox Poten- tial	Depth (m)	Simp- son's diver- sity index	Num- ber of spe- cies	Ammo- bacu- lites sp.	Ammo- nia parkin- soniana tepida	Ammo- nia parkin- soniana typica	A. parkin- soniana (typica + tepida)	Amphi- stegina les- sonii
North Biscayne Bay														
BB02	25 56'40	80 07'40	30.73	32.10	5.82	454	3.60	0.11	29	0.31	8.49	1.26	9.75	0.00
BB03	25 55'44	80 07'53	30.49	33.50	5.89	470	1.40	0.32	21	0.00	0.00	54.43	54.43	0.00
BB04	25 55'02	80 07'33	29.92	35.20	5.52	462	4.40	0.15	24	1.73	0.00	29.41	29.41	3.81
BB05A	25 54'04	80 08'32	30.12	33.50	5.89	401	0.90	0.25	11	0.00	23.26	36.92	60.18	0.00
BB09	25 52'15	80 09'19	30.50	32.70	5.71	459	1.90	0.40	11	0.00	0.00	50.14	50.14	0.00
BB10	25 52'09	80 08'38	30.22	33.60	6.21	460	2.20	0.17	24	0.00	34.08	0.00	34.08	0.00
BB11	25 50'46	80 10'01	30.31	32.00	5.60	450	1.50	0.39	11	0.00	0.00	49.58	49.58	0.00
BB14	25 49'46	80 09'31	29.37	32.40	4.54	433	0.60	0.35	15	0.00	0.00	46.39	46.39	0.00
BB15	25 48'52	80 10'31	29.90	31.10	3.74	461	3.20	0.49	9	0.60	0.00	65.26	65.26	0.00
BB17	25 48'08	80 09'58	29.96	31.80	6.00	440	0.90	0.35	13	0.00	0.00	52.15	52.15	0.00
Central Biscayne Bay														
SP01	25 39'28	80 16'06	30.25	29.50	4.18	393	3.10	0.23	15	0.00	16.83	33.65	50.48	0.00
BB22	25 45'21	80 10'28	30.00	33.80	5.60	458	1.90	0.22	19	0.00	0.00	42.28	42.28	0.00
BB26	25 44'50	80 11'06	29.87	33.40	5.55	473	2.00	0.13	26	0.96	8.04	28.30	36.33	0.00
BB34	25 39'03	80 15'33	30.25	32.00	4.34	419	2.10	0.11	20	0.00	0.00	0.00	0.00	0.00
BB35	25 38'37	80 11'30	30.01	37.00	5.71	449	1.70	0.08	25	0.00	4.69	0.00	4.69	0.00
BB36	25 35'58	80 14'11	29.90	37.40	5.82	439	2.30	0.15	26	0.00	0.00	0.00	0.00	0.00
BB37	25 34'13	80 11'31	29.54	37.20	5.56	451	1.80	0.08	29	0.00	0.00	0.00	0.00	0.00
South Biscayne Bay														
BB41	25 28'20	80 17'04	29.76	38.50	6.04	310	2.10	0.12	21	0.00	0.00	0.27	0.27	0.00
BB42	25 27'23	80 11'59	29.19	37.30	5.63	455	1.30	0.24	19	0.00	0.00	0.00	0.00	0.00
BB44	25 24'02	80 15'20	29.67	37.60	5.53	448	2.10	0.15	26	0.00	0.00	0.33	0.33	0.00
BB45	25 22'09	80 16'48	29.60	37.40	5.37	458	2.40	0.11	21	0.00	0.00	0.00	0.00	0.00
BB48	25 18'29	80 20'56	29.37	32.40	5.38	415	2.60	0.14	24	0.00	0.32	0.63	0.95	0.00
BB51	25 15'04	80 24'51	29.72	22.20	7.11	444	1.50	0.26	12	0.00	0.00	25.00	25.00	0.00

fig. 2; SFWMD, 1994) occur in Central Biscayne Bay. These are supported on substrates including calcareous and quartz sands, calcareous mud, and organic-rich muds (Wanless, 1976). Salinities within Central Biscayne Bay range from 32.0 to 37.4 ppt in the open-bay and 29.5 ppt at the discharge of Snapper Creek Canal (Text-fig. 3; Table 1). Average August salinity since 1988 in the open-bay is 35.90 ppt. The coastal regions of Central Biscayne Bay vary significantly dependent on point-source freshwater run-off. The northern part of Central Biscayne Bay is strongly influenced by the Miami River, which accounts for the high turbidity, high nutrient, and high pollutant levels in this region. Further south, Snapper Creek, Coral Gables Waterway, and Cutler Drain have been identified as pollutant point-sources (SFWMD, 1994). However, flushing of these regions occurs on a regular basis due to Government and Norris Cuts. The southern part of Central Biscayne Bay becomes more pristine and includes Biscayne National Park. Significant effects on the ecosystem in this region are localized, many related to watercraft use such as sewage and solid waste

disposal, fuel leakage and spillage, and propeller scouring of seagrass beds.

South Biscayne Bay includes the southern portion of Biscayne National Park and the northern part of the Florida Keys National Marine Sanctuary (Barnes and Card Sounds; Text-fig. 1). Sediments in South Biscayne Bay include non-tidal mud banks, calcareous mud, and sands (Wanless, 1976), and they support seagrass and seagrass with hard-bottom matrix communities (Text-fig. 2; SFWMD, 1994). Salinities range from between 38.5 and 37.3 ppt north of Card Sound, to less than 30 ppt in Barnes Sound with average August salinity since 1989 in Barnes Sound at 28.80 ppt (Text-fig. 3; Table 1). Although not as severely affected by urbanization as the North and Central Bay, Southern Biscayne Bay is affected by channelized freshwater input and nutrient enrichment from the canal systems. In addition, Card and Barnes Sounds are very restricted, thus reducing their flushing cycles. Other factors that influence the ecosystem of South Biscayne Bay are pollutants from adjacent landfills,

Table 1.—Extended.

Sample	<i>Archaias angulatus</i>	<i>Articulina mucronata</i>	<i>Astigerina</i> sp.	<i>Astro- nonion stellatum</i>	<i>Bolivina lowmani</i>	<i>Bolivina pseudo- plicata</i>	<i>Bolivina pseudo- punctata</i>	<i>Bolivina</i> sp.	<i>Bolivina striatula</i>	<i>Bulinina marginata</i>	<i>Bulinina striata</i>	<i>Bulinina elegans</i>	<i>Cassidulina</i> sp.	<i>Cibicides</i> sp.	<i>Clavulina</i> sp.
North Biscayne Bay															
BB02	0.00	0.00	0.00	0.00	0.31	0.94	5.66	0.00	4.09	1.89	0.00	1.57	0.00	0.63	0.00
BB03	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB04	15.92	0.00	2.42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB05A	0.00	0.00	0.00	10.47	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB09	0.00	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB10	2.24	1.79	0.00	0.00	0.00	0.45	0.90	0.00	0.45	0.00	0.00	0.45	1.35	0.00	0.00
BB11	0.00	0.85	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB14	0.00	1.88	0.00	0.00	0.00	0.00	0.00	0.00	1.25	0.63	0.00	0.00	0.00	0.00	0.00
BB15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB17	0.33	0.99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Central Biscayne Bay															
SP01	0.00	0.00	0.63	0.00	0.32	0.00	0.00	0.32	0.00	0.00	0.00	0.32	0.00	0.00	0.00
BB22	0.00	1.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB26	0.00	0.64	0.00	0.00	1.93	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB34	12.58	3.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.65
BB35	12.64	2.17	1.08	0.00	0.00	0.00	0.00	0.00	1.81	0.00	0.00	0.36	0.00	0.00	0.00
BB36	32.23	0.66	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00
BB37	18.18	4.17	0.00	0.00	0.38	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.89
South Biscayne Bay															
BB41	26.08	0.27	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB42	45.23	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB44	32.89	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.33
BB45	20.86	1.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00
BB48	1.59	4.76	0.00	0.00	0.32	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB51	0.00	0.82	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

the Turkey Point power facility, and propeller scour in shallow regions.

An additional consideration with respect to the Biscayne Bay ecosystem is the impact of ground water. Ground water seepage at the coastal margins and from subsurface springs has been noted historically (Kohout and Kolipinski, 1967). This acts as an additional source of fresh water, but also may provide an additional source of contaminants by pollutant-enriched ground water. A significant source of groundwater discharge is apparent along the coastal margin of Central Biscayne Bay (V. Quinones, USGS, personal communication).

The factors listed above play a primary role in the distribution of aquatic communities within the Biscayne Bay ecosystem (SFWMD, 1994). The identification of the significant factors in controlling the distributions of the Bay's biogenic components is critical for our interpretation and understanding of the evolution of the Biscayne Bay ecosystem. This paper presents the modern distributions of benthic foraminifera and their environmental controls within Biscayne Bay.

METHODOLOGY

A systematic collection of surficial sediment samples from Biscayne Bay was conducted in collaboration with Metropolitan Dade County Department of Environmental Resources Management (DERM) during the months of June and August, 1996. A total of twenty-three localities (Text-fig. 1; Table 1) were sampled for surficial sediments using an Eckman Grab sampler. These sites have been sampled monthly starting in 1988 (DERM Bay Run Program) for a variety of water-quality variables of which the following are reported herein: salinity, temperature, dissolved oxygen, and oxygen-reduction potential (redox) (Table 1).

Approximately 100 cubic centimeters (cc) of the upper two centimeters of the grab samples were disaggregated and sieved through a 63 μ m sieve. The greater than 63 μ m size fraction was recovered, dried at 50°C, and analyzed for foraminifera. More than 300 foraminifer specimens were picked randomly using a 45 compartment picking tray and random number table. Samples not producing greater than 300 specimens

Table 1.—Extended.

Sample	<i>Cribo-</i> <i>stom-</i> <i>oides</i> sp.	<i>Cyclo-</i> <i>gyra</i> <i>plan-</i> <i>orbis</i>	<i>Discor-</i> <i>bis</i> <i>mira</i>	<i>Elphi-</i> <i>dium</i> <i>cf.</i> <i>adven-</i> <i>um</i>	<i>Elphi-</i> <i>dium</i> <i>delica-</i> <i>tulum</i>	<i>Elphi-</i> <i>dium</i> <i>galve-</i> <i>sonense</i> <i>typicum</i>	<i>Elphi-</i> <i>dium</i> <i>galve-</i> <i>stonense</i> <i>mexi-</i> <i>canum</i>	<i>Elphi-</i> <i>dium</i> <i>poe-</i> <i>y-</i> <i>anum</i>	<i>Flori-</i> <i>lus</i> <i>auri-</i> <i>culus</i>	<i>Fursen-</i> <i>koina</i> <i>sp.</i>	<i>Gaud-</i> <i>ry-</i> <i>ina</i> <i>exilis</i>	<i>Globo-</i> <i>cassi-</i> <i>dulina</i> <i>subglo-</i> <i>bosa</i>	<i>Milio-</i> <i>linella</i> <i>circu-</i> <i>laris</i>	<i>Milio-</i> <i>linella</i> <i>fich-</i> <i>teliana</i>	<i>Milio-</i> <i>linella</i> <i>labiosa</i>
North Biscayne Bay															
BB02	0.00	1.26	4.72	0.00	2.52	0.00	0.94	0.00	0.00	2.20	2.83	1.26	1.26	0.00	0.94
BB03	0.63	0.00	0.00	3.80	0.00	7.28	5.70	0.32	0.95	0.00	0.32	0.00	0.00	0.00	0.00
BB04	0.00	0.00	1.38	0.35	0.00	0.00	14.88	0.35	0.35	0.00	0.69	0.00	0.00	0.00	2.08
BB05A	0.00	0.00	0.00	0.00	0.00	0.00	21.80	0.00	0.87	0.00	0.00	0.00	0.00	0.00	0.00
BB09	0.00	0.00	0.00	0.00	0.00	0.00	37.97	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB10	0.00	0.00	4.48	0.00	8.07	0.00	0.00	0.45	0.00	0.90	0.00	0.45	0.00	0.00	0.00
BB11	0.00	0.00	0.00	0.00	0.00	0.28	37.18	0.00	0.00	0.00	0.00	0.00	0.85	0.00	0.00
BB14	0.00	0.00	0.00	0.00	0.00	2.19	35.74	0.00	0.00	0.00	0.00	0.00	0.31	0.00	0.94
BB15	0.00	0.00	0.00	0.00	1.81	0.00	25.68	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.81
BB17	0.00	0.00	0.00	0.00	0.00	0.00	24.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	10.56
Central Biscayne Bay															
SP01	0.00	0.00	0.00	0.00	0.00	25.71	1.27	0.00	0.00	0.00	0.00	0.00	0.32	0.00	0.00
BB22	0.00	0.67	0.00	0.00	0.00	6.04	16.11	0.00	0.67	0.00	0.00	0.00	1.34	0.00	0.00
BB26	0.00	0.00	0.32	0.00	1.61	9.65	13.18	0.00	2.89	0.32	0.00	0.00	1.61	0.00	0.64
BB34	0.00	0.00	0.00	2.26	0.00	0.00	0.00	0.65	0.00	0.00	0.00	0.00	0.65	0.65	1.61
BB35	0.00	0.00	0.00	0.00	0.00	10.83	1.81	0.00	1.81	0.00	0.00	0.36	0.00	0.00	0.00
BB36	0.00	0.00	0.66	0.33	0.00	0.00	2.99	0.00	0.00	0.00	0.00	0.00	2.99	0.00	1.33
BB37	0.00	0.00	0.00	0.38	0.00	0.00	0.00	1.52	0.00	0.00	0.00	0.00	8.33	0.38	0.00
South Biscayne Bay															
BB41	0.00	0.00	0.00	0.27	0.00	0.00	2.42	1.08	0.00	0.00	0.00	0.00	11.83	0.00	0.00
BB42	0.00	0.00	0.00	0.00	1.41	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.41	0.00	0.35
BB44	0.00	0.00	1.00	0.00	2.33	0.00	1.00	0.66	0.00	0.00	0.00	0.00	3.99	0.00	0.00
BB45	0.00	0.00	0.00	1.43	8.86	0.00	0.00	2.00	0.00	0.00	0.00	0.00	2.57	0.00	0.86
BB48	0.00	0.00	0.00	0.63	27.30	0.00	3.17	0.00	0.00	0.00	0.00	0.00	13.02	0.00	0.00
BB51	0.00	0.00	0.00	0.00	0.00	0.00	41.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23

were picked of all their specimens and used in this study if they exceeded 50 counts (Table 1). The foraminifera were identified based primarily on Bock (1971) and Poag (1981), counted, and species counts were standardized to percent of total assemblage (Table 1) and used as such in the quantitative analyses. Because the results of the analyses presented here are the basis on which future downcore paleoenvironmental analyses will be interpreted, total assemblage data is presented. This is consistent with the findings of Scott and Medioli (1980) who concluded that total assemblage data more accurately represent prevailing modern conditions and are more useful for paleoenvironmental studies.

The foraminiferal data were analyzed using two statistical techniques, hierarchical cluster analysis and principal components analysis (PCA). The hierarchical clustering method, complete linkage of the Pearson correlation similarity coefficient was applied to the foraminiferal data to identify distinct sample groupings (Q-mode) and foraminiferal assemblages (R-mode). Q-mode varimax principal component analysis of the Pearson correlation similarity matrix was used to de-

termine the robustness of the foraminiferal groupings defined in the cluster analyses and to quantify the data in multi-dimensional space, which places environmental constraints on the faunal distributions.

BENTHIC FORAMINIFERAL RESULTS

A total of 69 taxa of benthic foraminifers common to the North American southeast coast and Gulf of Mexico were identified from the Biscayne Bay modern sediment samples (Table 1). Species diversity, as measured using Simpson's index (Simpson, 1949), ranged from 0.080 to 0.493. Simpson's index is useful in that it identifies dominance patterns within the data. Combined with the number of species present the Simpson's index should reflect low diversity, high dominance assemblages associated with stress conditions and low dominance, high diversity assemblages associated with normal marine conditions.

Rotaliid forms dominate the foraminiferal assemblages with agglutinated taxa constituting a minor component in most of the assemblages. Species dominance varies considerably throughout the Bay with *Ammonia parkinsoniana* and *Elphidium galvestonense*

Table 1.—Extended.

Sample	<i>Nodo- bacular- iella</i> sp.	<i>Nodo- sari- idae</i>	<i>Nonio- nella</i> sp.	<i>Nubecu- laria</i> <i>luci- fuga</i>	<i>Patel- lina</i> <i>corru- gata</i>	<i>Penero- plis</i> <i>proteus</i>	Plank- tonic	<i>Pseudo- clave- lina</i> <i>gracilis</i>	<i>Pyrgo</i> <i>denti- culata</i>	<i>Pyrgo</i> <i>serrata</i>	<i>Pyrgo</i> <i>sub- sphaer- ica</i>	<i>Quin- quelo- culina</i> <i>agglu- tinans</i>	<i>Quin- quelo- culina</i> <i>bos- ciana</i>	<i>Quin- quelo- culina</i> <i>poeyana</i>	<i>Quin- quelo- culina</i> <i>poly- gona</i>
North Biscayne Bay															
BB02	0.00	0.94	8.18	0.00	0.31	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.72	1.26	0.00
BB03	0.00	0.00	0.00	0.00	0.00	0.00	0.63	0.00	0.00	0.00	0.32	0.00	0.63	0.63	0.63
BB04	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.77	3.11	1.73	0.35	2.08
BB05A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.03	0.29	1.45	0.87	0.00
BB09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	0.29	1.45	0.29
BB10	0.00	0.00	0.00	0.00	0.00	0.45	0.00	0.00	0.00	0.00	0.00	1.35	5.38	2.24	0.90
BB11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.28	0.85	0.00	0.00	0.00
BB14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.31
BB15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.91	0.00	1.21	0.00
BB17	0.00	0.00	0.00	0.00	0.33	0.00	0.00	0.00	0.00	0.00	0.00	0.66	0.33	0.66	0.00
Central Biscayne Bay															
SP01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.95
BB22	0.00	0.00	0.00	0.00	0.00	1.68	0.00	0.00	0.00	0.00	4.03	2.35	5.70	1.34	0.00
BB26	0.00	0.00	0.00	0.00	0.00	0.32	0.32	0.00	0.00	0.32	1.29	0.64	6.11	4.18	3.22
BB34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.26	0.00	6.13	3.87	1.61	3.87	3.87
BB35	0.00	0.00	0.00	0.36	0.00	0.00	0.00	0.00	0.00	0.00	0.72	6.14	9.03	8.66	5.05
BB36	0.00	0.00	0.00	0.00	0.00	2.66	0.00	0.00	0.00	0.33	0.33	2.99	3.32	10.63	7.97
BB37	0.00	0.00	0.00	0.00	0.00	7.58	0.00	1.52	0.38	0.76	0.76	3.41	3.41	3.03	3.79
South Biscayne Bay															
BB41	0.00	0.00	0.00	0.00	0.00	1.61	0.00	0.00	0.27	0.00	2.15	2.69	4.03	5.38	8.06
BB42	0.00	0.00	0.00	0.00	0.00	8.13	0.00	0.00	0.00	0.35	2.83	8.48	2.83	2.83	4.59
BB44	0.33	0.00	0.00	0.00	0.00	1.00	0.00	0.00	0.33	0.00	1.99	6.31	5.32	6.31	3.65
BB45	0.00	0.00	0.00	0.00	0.00	2.00	0.00	0.00	0.00	0.00	3.43	2.00	7.43	6.86	6.86
BB48	0.00	0.00	0.32	0.32	0.00	0.32	0.00	0.00	0.63	0.00	0.32	0.63	18.41	8.89	2.54
BB51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.23	4.51	0.00	7.79	2.46

constituting over 50% of the fauna in much of Northern Biscayne Bay and Barnes Sound where the Simpson's index range from 0.114 to 0.493. Conversely, *Archaias angulatus* is dominant (up to 45%) in samples collected from the open regions of Biscayne Bay where Simpson's index averages ~0.011. Other calcareous hyaline forms include *Bolivina* spp., *Elphidium delicatulum*, *Rosalina floridana*, and *R. globularis*. Common miliolids include *Articulina mucronata*, *Miliolinella circularis*, *M. labiosa*, *Pyrgo sub-sphaerica*, *Quinqueloculina agglutinans*, *Q. bosciana*, *Q. poeyana*, *Q. polygona*, *Q. seminula*, *Q. tenagos*, and *Triloculina* spp. Soritids present are *Archaias angulatus*, *Peneroplis proteus*, and *Sorites marginalis*. Agglutinated taxa in Biscayne Bay include *Ammobaculites* sp., *Clavulina tricarinata*, *Pseudoclavulina gracilis*, *Textularia candeiana*, *T. conica*, and *Trochammina* spp.

Results of the quantitative analyses of the benthic foraminifer data are shown in Text-figure 4 and Table 2. Q-mode cluster analysis defines two sample groups or biotopes (Text-fig. 4a) with two sample outliers. Biotope one consists of samples from Central and

northern South Biscayne Bay (BB34, BB35, BB36, BB37, BB41, BB42, BB44 and BB45; Text-fig. 4a) and represent open-marine conditions. The second biotope consists of samples from restricted environments or regions greatly effected by point-source freshwater input (SP01), North Biscayne Bay, and Barnes Sound (BB3, BB4, BB5A, BB9, BB10, BB11, BB14, BB15, BB17, BB22, BB26, BB51 and SP01; Text-fig. 4a). One outlier sample, BB02, is from Dumbfoundling Bay, the northernmost sample locality. Sample BB48 is the second outlier and is from Card Sound, Southern Biscayne Bay.

R-mode cluster and principal components (PC) analyses result in the definition of four major groups of benthic foraminifers or assemblages (Text-fig. 4b). The first group, Cluster 1, contains several significant species including *Peneroplis proteus*, *Triloculina* spp., *Miliolinella circularis*, *Articulina mucronata*, *Quinqueloculina subpoeyana*, and *Q. bosciana* (Text-fig. 4b) that have high positive PC1 and PC4 loadings (Table 2). Cluster 2 contains *Quinqueloculina polygona*, *Q. agglutinans*, *Q. tenagos*, *Q. poeyana*, *Archaias angulatus*, and *Rosalina floridana* that have high positive

Table 1.—Extended.

Sample	<i>Quinqueloculina seminula</i>	<i>Quinqueloculina poeyana</i>	<i>Quinqueloculina tenagos</i>	<i>Rectobolivina advena</i>	<i>Recurvoides</i> sp.	<i>Rosalina floridana</i>	<i>Rosalina globularis</i>	<i>Spirosigmoilina antillarum</i>	<i>Spiroloculina</i> sp.	<i>Sorites marginalis</i>	<i>Stainforthia complanata</i>	<i>Triloculina lineiana</i>	<i>Triloculina placiana</i>	<i>Triloculina rotunda</i>	<i>Triloculina tricarinata</i>
North Biscayne Bay															
BB02	27.67	0.00	0.00	0.00	0.00	9.75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.20
BB03	4.11	0.00	6.96	0.32	0.32	2.22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.22
BB04	0.69	0.00	1.73	0.00	0.00	2.08	0.00	0.00	0.00	0.00	0.00	0.35	0.00	0.69	8.30
BB05A	1.45	0.00	0.58	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
BB09	2.32	0.00	1.45	0.00	0.00	0.29	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.22
BB10	17.94	0.00	4.48	0.00	0.00	6.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.45	3.59
BB11	0.85	0.00	3.94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.41	3.94
BB14	3.45	0.00	4.39	0.00	0.00	0.63	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.31	0.63
BB15	1.81	0.00	0.30	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.30	0.00
BB17	0.00	0.00	2.97	0.00	0.00	0.00	1.32	0.33	0.00	0.00	0.00	0.00	0.00	0.00	4.62
Central Biscayne Bay															
SP01	13.02	0.00	0.95	0.00	0.00	2.54	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.27
BB22	7.38	0.00	1.34	0.00	0.00	2.35	0.00	0.00	0.00	0.34	0.00	0.67	0.00	1.34	2.68
BB26	6.43	0.00	0.32	0.00	0.00	1.61	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.50
BB34	0.00	0.00	8.71	0.00	0.00	20.97	0.00	0.32	0.00	0.00	0.00	0.65	0.00	0.00	16.13
BB35	7.58	0.00	0.36	0.00	0.00	6.50	0.00	0.00	0.00	0.36	0.72	1.08	1.44	1.08	12.64
BB36	13.62	0.00	1.00	0.00	0.00	1.99	0.00	0.00	0.66	0.33	0.00	0.33	0.00	0.66	8.64
BB37	0.76	1.89	9.09	0.00	0.00	9.47	0.00	1.89	1.14	0.76	0.00	7.20	1.89	1.14	1.14
South Biscayne Bay															
BB41	8.87	0.00	1.88	0.00	0.00	4.57	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.27	12.90
BB42	8.13	0.00	2.12	0.00	0.00	2.12	0.00	0.00	0.00	0.35	0.00	0.00	0.35	0.00	1.06
BB44	4.65	0.00	2.33	0.00	0.00	2.33	0.00	0.00	0.00	0.00	0.00	0.66	0.00	2.33	12.96
BB45	5.71	0.00	2.29	0.00	0.00	3.71	0.00	0.00	0.00	0.29	0.00	0.00	0.00	0.29	17.71
BB48	2.54	0.00	0.32	0.00	0.00	5.71	0.00	0.95	0.00	0.00	0.00	0.00	0.00	2.86	3.49
BB51	10.25	0.00	0.00	0.00	0.00	2.87	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.64

PC3 and PC4 loadings (Text-fig. 4b, Table 2). The third cluster includes *Bolivina* spp., *Bulimina marginata*, *Buliminella elegantissima*, and *Fursenkoina* sp. that have high PC2 loadings (Text-fig. 4b, Table 2). The fourth cluster is composed predominantly of *Ammonia parkinsoniana*, *Elphidium galvestonense*, and *Ammobaculites exiguus* that are represented by high negative PC3 and PC4 loadings (Text-fig. 4b, Table 2).

In the R-mode principal components analysis the first four principal components explain 94 percent of the variance in the data set (Table 2). High positive and negative (greater than 0.5 and -0.5) principal component one (PC1) and principal component four (PC4) scores were obtained by foraminiferal species common to normal marine salinities and found on the continental shelf of the southeastern seaboard of the United States (Schnitker, 1971). Several of these species also are associated with epiphytal habitats. Species with high principal component two (PC2) scores are common to areas with high surface productivity and organic-rich, fine-grained sediments. Principal component three (PC3) contains species with high positive and negative scores that have specific salinity

preferences. High negative scores are associated with the species *Ammonia parkinsoniana* and *Elphidium galvestonense*, taxa associated with salinities ranging from 5 to 25 parts per thousand (ppt) in the south Florida region. Foraminifera associated with subtropical to tropical marine conditions (salinities ~ 35 ppt) have high positive PC3 scores.

DISCUSSION

Few studies have considered the distribution of foraminifera within Biscayne Bay. Bush (1958) presented a descriptive account of benthic foraminifera from Biscayne Bay by defining thirteen biotopes. Cole (1972) observed benthic foraminifera from a specific locality and attributed test deformation within benthic foraminiferal populations to thermal stress associated with power plant discharge. Benthic foraminiferal studies from Florida Bay (Bock, 1971; Rose and Lidz, 1977; Lidz and Rose, 1989) showed foraminiferal distributions associated with physiographic features and salinity conditions within the Bay. Results of the benthic foraminiferal analyses presented herein indicate

Table 1.—Extended.

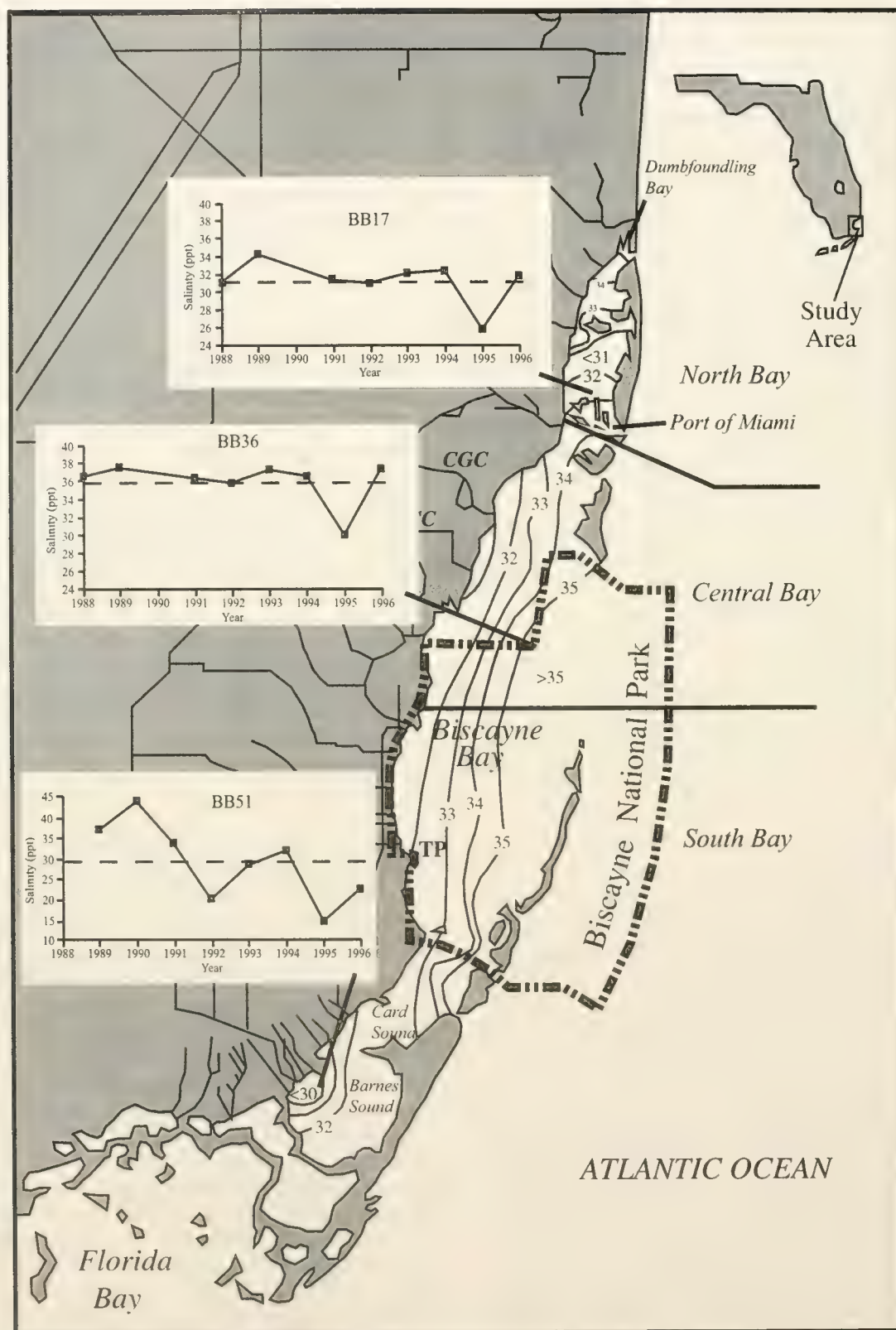
Sample	<i>Textu- laria candeiana</i>	<i>Textu- laria conica</i>	<i>Trocham- mina inflata</i>	<i>Trocham- mina</i> sp.	<i>Trocham- mina squamata</i>	Unident- ified	<i>Uvigerina</i> sp.	<i>Valvulina</i> sp.	<i>Valvulin- eria laevigata</i>	<i>Wiesner- ella</i> sp.	Counts
North Biscayne Bay											
BB02	0.31	0.00	0.00	0.00	0.00	0.00	0.94	0.00	0.00	0.63	318
BB03	0.00	0.00	6.96	0.00	0.00	0.00	0.00	0.00	0.00	0.00	316
BB04	2.77	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	289
BB05A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	344
BB09	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	345
BB10	0.00	0.45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	223
BB11	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	355
BB14	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	319
BB15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	331
BB17	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	303
Central Biscayne Bay											
SP01	0.00	0.00	0.00	0.00	0.32	0.00	0.00	0.00	1.59	0.00	315
BB22	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	298
BB26	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.64	311
BB34	0.00	0.00	0.00	0.00	0.00	0.00	0.00	9.35	0.00	0.00	310
BB35	0.00	0.72	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	277
BB36	0.00	0.66	0.00	0.00	0.00	0.00	0.00	1.00	0.00	1.33	301
BB37	0.00	3.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	264
South Biscayne Bay											
BB41	0.00	0.00	0.00	0.27	0.00	0.00	0.00	4.84	0.00	0.00	372
BB42	0.00	0.00	0.00	0.00	0.00	0.00	0.00	7.42	0.00	0.00	283
BB44	0.00	0.00	0.00	0.00	0.00	0.33	0.00	5.32	0.00	0.33	301
BB45	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.14	0.00	0.00	350
BB48	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	315
BB51	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.41	0.00	0.00	244

distinct distribution patterns associated with salinity and productivity.

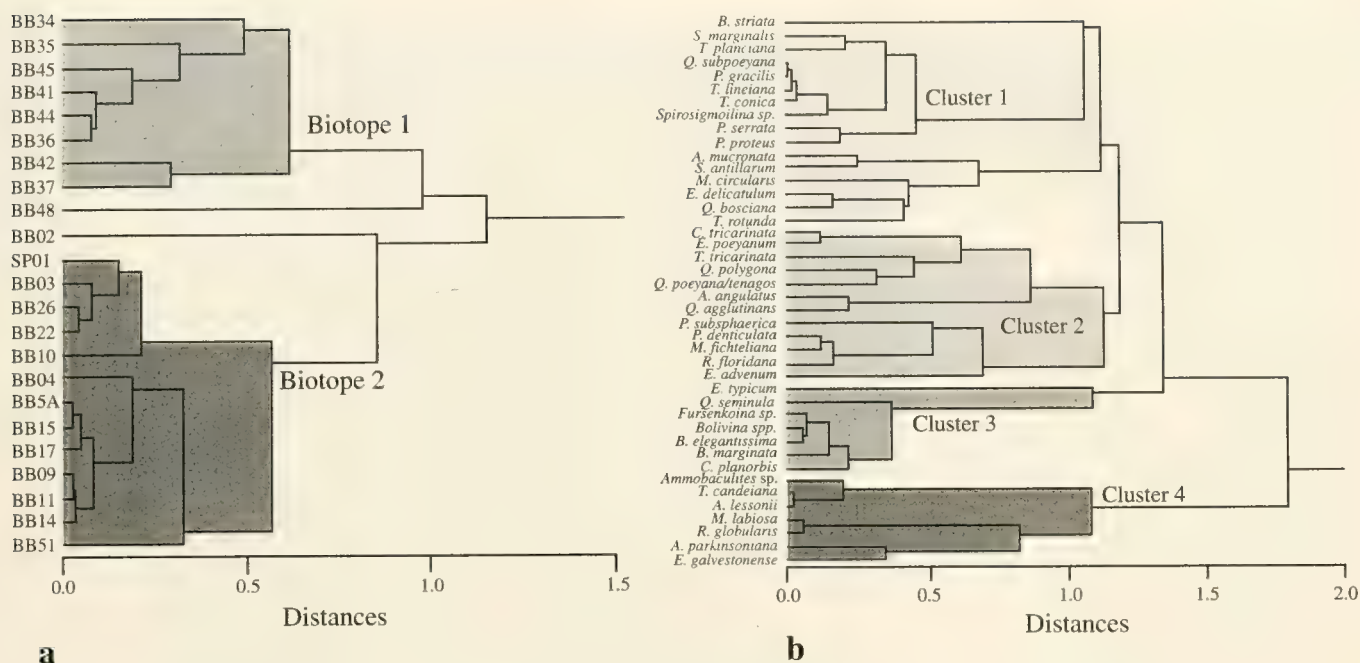
The easiest explained grouping is Cluster 4, with species having high negative PC3 and PC4 scores, *Ammonia parkinsoniana*, *Elphidium galvestonense*, and *Ammobacculites* sp. are interpreted as being controlled by salinity. Studies from Florida Bay (Rose and Lidz, 1977; Lidz and Rose, 1988; Brewster-Wingard and Ishman, 1999) and the Gulf Coast (Poag, 1981) indicate that these taxa are dominant in low salinity (<25 ppt) environments. These taxa are dominant in the samples that represent Biotope 2, samples from North Biscayne Bay, the outflow from Snapper Creek (SP01), and Barnes Sound, areas of restricted environments or near point-source freshwater input (Text-fig. 5) where salinities less than 35 ppt persist throughout the year. The distribution of these taxa in Biscayne Bay is consistent with their distribution in Florida Bay and other regions.

Conversely, Clusters 1 and 2 are composed of taxa associated with more normal marine conditions (salinities ~35 ppt), *Articulina mucronata*, *Archaias angulatus*, *E. delicatulum*, *M. circularis*, *P. proteus*, *Q. po-*

lygona, *Q. agglutinans*, *Q. bosciiana*, *Q. poeyana*, *Q. subpoeyana*, *Q. tenagos*, *T. lineiana*, *T. rotunda*, *T. tricarinata*, and *S. antillarum*. These taxa comprise the assemblages found in Biotope 1 from Central and northern South Biscayne Bay (Text-fig. 5). Several of these taxa, *A. mucronata*, *T. lineiana*, *Q. bosciiana*, *Q. poeyana*, and *Q. polygona* in Cluster 1 are commonly associated with normal marine conditions on the southeastern U.S. continental shelf (Schnitker, 1971; Murray, 1991). In addition, at least two of these species, *M. circularis* and *P. proteus*, have epiphytal habitats in lagoonal environments (Brasier, 1975a). The species representing these two clusters have high positive PC1, PC3, and PC4 scores. This indicates that the distribution of these species is partially controlled by normal marine salinity and the presence of seagrass. However, it may also be that the distinction between Clusters 1 and 2 represents a separation between a Central Biscayne Bay assemblage (1), influenced by an inflow of Atlantic shelf water, and a more southerly assemblage (2) with greater affinities to higher salinity assemblages found in Florida Bay. This pattern is consistent with the molluscan distributions in Biscayne



Text-figure 3.—Map of the Biscayne Bay region of South Florida showing August 1988 through 1996 salinity distributions in parts-per-thousand (ppt). The salinity contours represent August 1996.



Text-figure 4.—Dendrograms showing the results of the (a) Q-mode and (b) R-mode cluster analyses.

Bay that show much stronger affinities to Atlantic margin faunas than Florida Bay faunas (Brewster-Wingard, USGS, personal communication).

Cluster 3 contains an assemblage that has high PC2 scores (Table 2), is restricted to one sample from Biscayne Bay, BB02, and represents one of the outliers on the Q-mode cluster (Text-fig. 4a). It is distinguished by the only occurrence of *Bulimina marginata*, *Bolivina* spp., and *Fursenkoina* sp. in Biscayne Bay. Morphometric studies (Bernhard, 1986; Corliss and Chen, 1988) indicate that bolivinids are associated with organic rich, low oxygen environments. Their distributions are commonly associated with organic-rich sediments, as is *B. marginata* in the Gulf of Mexico (Phleger, 1951), South Atlantic (Mackensen *et al.*, 1993), and eastern Pacific (Phleger and Soutar, 1973). Sample BB02 is from the northernmost part of Biscayne Bay, Dumbfoundling Bay. This region is characterized by high chlorophyll-*a* values, particularly at site BB02. Canal input to North Biscayne Bay contains the highest concentrations of dissolved nitrates and phosphates in all of Biscayne Bay (Lietz, WRD, USGS personal communication). Other data indicate that North Biscayne Bay is a region of high organic sedimentation (Wanless *et al.*, 1984). Wanless *et al.* (1984) show the highest concentration of diatoms in North Biscayne Bay for a period from March 1982 through August 1983, with concentrations exceeding 600×10^3 /liter during November 1982. These values are an order of magnitude greater than those observed in South or Central Biscayne Bay, and are somewhat reflected in

the high weight percent total organic content (up to 29 percent) reported for North Biscayne Bay sediments (Wanless *et al.*, 1984). However, the coastal regions in Central and South Biscayne Bay are also rich in organic content (vegetative material) therefore making it necessary to distinguish organics from phytoplankton productivity versus macrofloral contribution. The distribution of the bolivinid taxa in Biscayne Bay indicates a relationship to phytoplankton productivity in Dumbfoundling Bay.

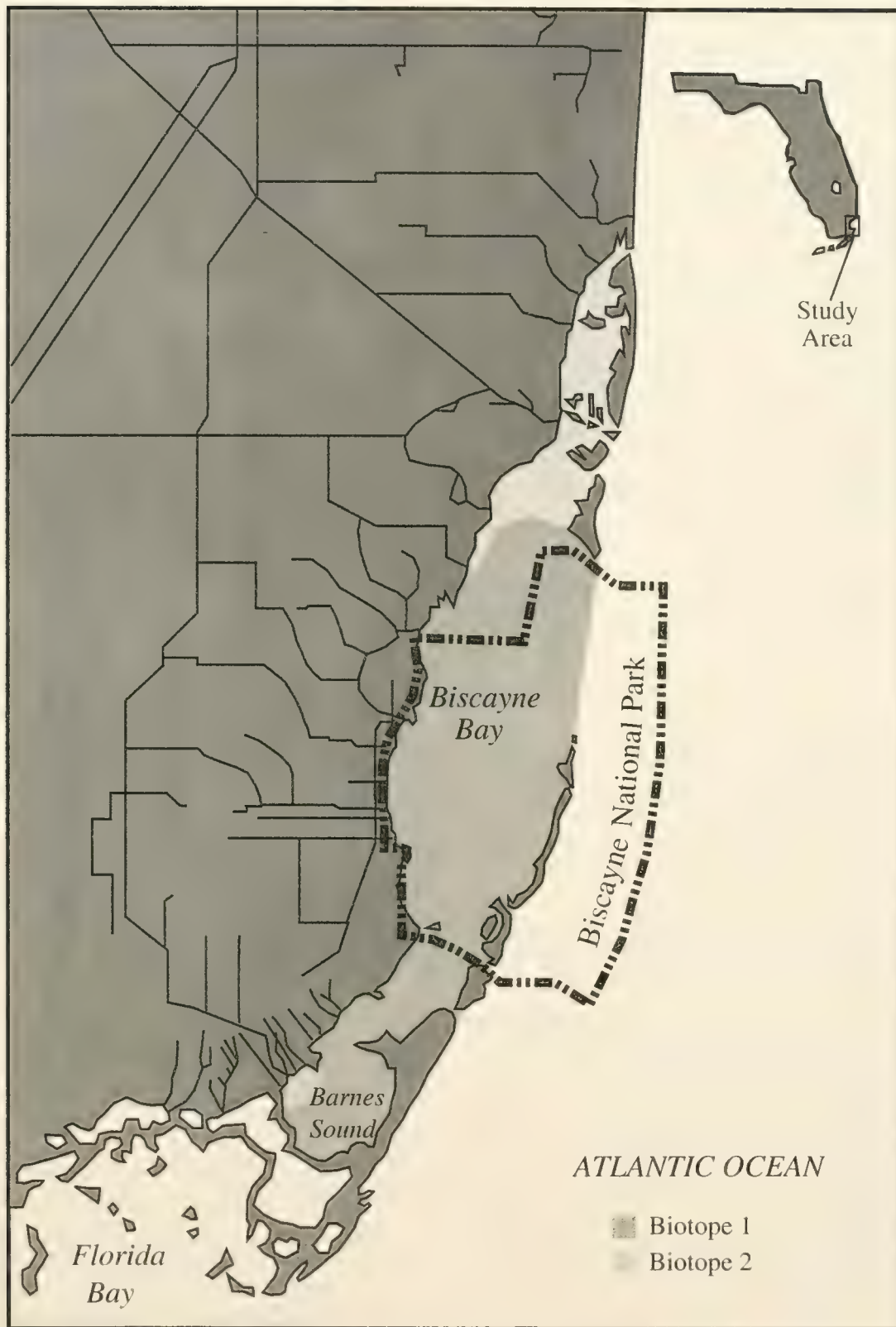
The benthic foraminiferal assemblages described in this study of Biscayne Bay foraminifera are somewhat consistent with previous results from Biscayne Bay, Florida Bay, and similar environments in the western Atlantic (Bush, 1958; Brasier, 1975a; Brasier, 1975b; Rose and Lidz, 1977) that emphasize substrate as a controlling factor. Brasier (1975a, 1975b) studied foraminiferal ecology and distributions in the environments surrounding Barbuda, West Indies, concluding that substrate was a strong controlling factor in the distribution of benthic foraminiferal assemblages. His three dominant substrate conditions were stable back-reef facies, consisting of fine-grained sediments that support a seagrass community in relatively clear water; mobile, bioclastic calcarenite substrate where diversity increases with increased seagrass density; and a high-energy, mobile, coarse bioclastic fore-reef substrate. Bush (1958) described thirteen benthic foraminiferal biotopes from Biscayne Bay: open-water east of the keys, tidally affected channel areas, turbulent shallow shoals, open-water shallow shoals, grass covered shoals, well-sorted

Table 2.—Result of the R-mode principal components analysis of the Biscayne Bay foraminiferal data showing the first 4 varimax rotated principal components, which account for 59% of the variance in the data.

Taxon	Principal component scores			
	PC1	PC2	PC3	PC4
<i>Trochammina conica</i>	-0.964	-0.002	-0.003	0.153
<i>Triloculina lineiana</i>	-0.938	0.044	0.056	0.147
<i>Spiroloculina</i> sp.	-0.907	0.004	0.041	0.068
<i>Sorites marginalis</i>	-0.874	0.038	0.194	0.017
<i>Triloculina planciana</i>	-0.850	0.020	0.052	0.108
<i>Spirosigmoilina antillarum</i>	-0.745	0.097	0.013	0.509
<i>Peneroplis proteus</i>	-0.741	0.053	0.295	-0.100
<i>Clavulina tricarinata</i>	-0.602	0.093	0.369	0.186
<i>Fursenkoina</i> sp.	0.082	-0.965	-0.084	0.024
<i>Bolivina</i> spp.	0.043	-0.963	-0.115	0.024
<i>Buliminella elegantissima</i>	0.051	-0.961	-0.092	0.016
<i>Nonionella</i> sp.	0.057	-0.942	-0.058	0.012
<i>Bulimina marginata</i>	0.065	-0.891	-0.124	-0.016
<i>Quinqueloculina seminula</i>	0.072	-0.848	0.011	-0.058
<i>Cyclogyra planorbis</i>	0.052	-0.841	-0.095	-0.002
<i>Discorbis mira</i>	0.090	-0.826	-0.007	-0.041
<i>Valvulina</i> sp.	0.111	0.116	0.821	-0.095
<i>Ammonia parkinsoniana</i>	0.326	0.237	-0.800	-0.234
<i>Triloculina tricarinata</i>	0.135	0.106	0.787	0.027
<i>Quinqueloculina polygona</i>	-0.261	0.102	0.743	-0.006
<i>Pyrgo subsphaerica</i>	0.106	0.206	0.740	-0.141
<i>Archaias angulatus</i>	-0.318	0.082	0.718	-0.265
<i>Quinqueloculina poeyanalténagos</i>	-0.385	0.187	0.641	0.409
<i>Pyrgo denticulata</i>	0.072	0.115	0.640	0.343
<i>Rosalina floridana</i>	-0.155	-0.318	0.629	0.317
<i>Quinqueloculina agglutinans</i>	-0.279	0.148	0.617	-0.243
<i>Elphidium galvestonense</i>	0.240	0.330	-0.615	-0.204
<i>Elphidium poeyanum</i>	-0.420	0.096	0.527	0.127
<i>Miliolinella fichteliana</i>	-0.332	0.093	0.506	0.173
<i>Elphidium delicatulum</i>	0.176	-0.053	0.078	0.787
<i>Articulina mucronata</i>	-0.377	0.132	0.248	0.771
<i>Quinqueloculina bosciana</i>	0.002	-0.161	0.266	0.713
<i>Miliolinella circularis</i>	-0.267	0.040	0.292	0.603
<i>Triloculina rotunda</i>	-0.123	0.122	0.101	0.588
<i>Textularia candeiana</i>	0.053	-0.053	0.089	-0.481
<i>Amphistegina lessonii</i>	0.047	0.052	0.095	-0.479
<i>Ammobaculites</i> sp.	0.104	-0.077	-0.030	-0.471
<i>Miliolinella labiosa</i>	0.086	0.129	-0.182	-0.174
<i>Elphidium advenum</i>	0.112	0.151	0.354	0.160
<i>Wiesnerella</i> sp.	-0.071	-0.425	0.124	-0.141
<i>Rosalina globularis</i>	0.044	0.159	-0.265	-0.046

sediment substrate, near-shore surface runoff, Bay deep-water axis, north bay, northeast bay, eastern margin, western bay, and southwestern bay. Cluster 1 is consistent with the composition of the back-reef biofacies of Brasier (1975a) and the channel areas, shallow shoals, vegetated shallow shoals, and well-sorted shoals biotopes of Bush (1958). These faunal associations are dominated by miliolids, particularly *Miliolinella circularis* that is associated with seagrass in this environment (Brasier, 1975a). Cluster 2 contains taxa similar to the mobile substrate biofacies of Brasier (1975a) and deep-water bay axis biotope of Bush (1958), and is characterized by *A. angulatus*, *Q. agglutinans*, and *E. poey-*

anum. In addition to the similarity in species composition, the Simpson's index decreases and species diversity of this assemblage increases as the density of seagrass increases and sediments become finer grained. Both Biscayne Bay assemblages contain species *A. angulatus* and *P. proteus*, which are considered epiphytal and commonly associated with *Thalassia* (Lee and Zucker, 1969; Levy, 1991; Steinker and Steinker, 1976). The spatial distribution of species such as *A. angulatus* and *E. poeyanum* in the current study may differentiate a seagrass-dominated substrate from a sediment dominated substrate, but does not indicate an absence of seagrass.



Text-figure 5.—Map of the Biscayne Bay region of South Florida showing the distribution of the biotopes in Biscayne Bay: Biotope 1 (dark shade) represents marine salinities; Biotope 2 (light shade) represents restricted circulation and oligohaline to polyhaline conditions.

Ammonia parkinsoniana and *Elphidium galvestonense* are dominant taxa (>25%) in samples from Biotope 2 in Northern Biscayne Bay, and Barnes Sound, Southern Biscayne Bay. The dominance of these taxa indicates conditions of high variability and relatively low salinity conditions. This assemblage is similar to the *Ammonia-Elphidium* assemblage (*A-E* assemblage) described from the Gulf of Mexico (Poag, 1981) and northeastern Florida Bay (Brewster-Wingard *et al.*, 1996). The *A-E* assemblage is associated with oligo- to mesohaline (0.5–18 ppt) environments. In contrast, benthic foraminiferal assemblages from the Gulf Coast (Poag, 1981) and Florida Bay (Brewster-Wingard *et al.*, 1996) that are dominated by miliolid taxa are associated with polyhaline to euhaline (18 to 35 ppt) conditions. Similarly, Brasier (1975a) found strong associations between foraminifera and salinity, where low salinity habitats typically contained *Ammonia beccarii*, and hypersaline habitats were dominated by miliolids *Quinqueloculina* spp. and *Triloculina* spp.

SUMMARY

Benthic foraminiferal analyses of 23 surficial sediment samples, collected from Biscayne Bay, indicate

four distinct foraminiferal assemblages identified using cluster and principal components analyses. The Cluster 4 assemblage is dominated by *Ammonia parkinsoniana* and *Elphidium galvestonense*, represents oligohaline to polyhaline conditions in areas where circulation is restricted and point-source freshwater input occurs. The Cluster 3 assemblage, characterized by the presence of *Bolivina* spp. and *Bulimina marginata*, represents high nutrient input and organic flux to the substrate. The Cluster 2 assemblage is dominated by miliolids with *Archaias angulatus* and *Elphidium poeyanum* significant faunal components with affinities to Florida Bay foraminiferal assemblages. The Cluster 1 assemblage also is dominated by miliolids in which *Articulina mucronata* and *Peneroplis proteus* are significant components. This assemblage has affinities with Atlantic shelf assemblages. The latter two assemblages represent polyhaline to euhaline conditions where seagrass is an important factor. These four assemblages recognized from the modern Biscayne Bay sediments will provide a basis on which the interpretation of historical changes in environmental conditions within Biscayne Bay can be made.

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CHAPTER 12

OSTRACODE SHELL CHEMISTRY AS A PALEOSALINITY PROXY IN FLORIDA BAY

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ABSTRACT

We investigated the use of ostracode metal/calcium ratios (Mg/Ca, Sr/Ca, and Na/Ca) to reconstruct the salinity history of central Florida Bay from its sedimentary record. We first developed provisional partition coefficients ($K_{D,Mg}$ and $K_{D,Sr}$) from the average me/Ca ratio for modern Florida Bay water and 171 modern shells of *Loxoconcha matagordensis* at a mean Florida Bay water temperature of 26.5°C. Trends in Mg/Ca ratios for *L. matagordensis* and *Peratocytheridea setipunctata* from radiometrically dated sediment cores from Russell Bank, Park Key, and Bob Allen Keys appear to provide a reasonable estimate of Florida Bay salinity history for the past 130 years. The most complete Mg/Ca record from Russell Bank extends back to 1875 and shows a good correspondence between estimated paleosalinity and measured annual rainfall in south Florida. Paleosalinity estimates for the Russell Bank area range from ~13 to ~55 ppt. Estimates for the post-1950s period are comparable to instrumental measurements of salinity near the Russell Bank site. The overall record indicates a decadal-scale variability in salinity in which large amplitude shifts in ostracode Mg/Ca ratios with high Mg/Ca (higher salinity) values corresponding to periods of low rainfall from ~1895 to ~1920 and from 1940 to present. The intervening 20 years (~1920–1940) are characterized by relatively low amplitude shifts in Mg/Ca and rainfall. Since 1950, periods of high salinity (~45 to ~55 ppt) occur during each decade. Prior to 1940, salinity never exceeded ~45 ppt and generally remained below 40 ppt, despite evidence in the rainfall record of dry intervals in the early 1900s equivalent to those of the last 50 years. Salinity minima associated with the decadal-scale oscillations range from ~15 to ~25 ppt. Four of the five extreme low values (~1915, ~1940, ~1983, ~1998) appear to correspond with times of strongly negative values of the Southern Oscillation Index, that is, El Niño conditions that bring anomalously high winter rainfall in the southeastern U.S.

These results support the hypothesis that seasonal and decadal-scale salinity fluctuations are a natural part of the Florida Bay ecosystem, and that these fluctuations are largely a function of natural variability of regional climate (rainfall). The relatively low peak salinity values associated with apparent dry periods in the early 1900s suggests that, since ~1950, anthropogenic factors may have played a role in the magnitude of the salinity fluctuations in more recent times.

INTRODUCTION

Salinity variations play an important role in the physical and biogeochemical processes of estuaries and marine embayments. Within these marginal marine settings, either directly or indirectly, spatial and temporal variations in salinity control turbidity and sedimentation, the distribution of dissolved inorganic and organic constituents, and the distribution and abundance of flora and fauna (reviews in Chester, 1990; Berner and Berner, 1996).

Recently, Florida Bay—an estuarine-like, shallow marine embayment that receives significant terrestrial runoff from peninsular Florida—has experienced dra-

matic ecosystem changes including sea-grass die-offs, decreases in populations of fishes, pink shrimp, and water birds, and increased blooms of algae (Boesch *et al.*, 1993). At the same time, the frequency and intensity of hypersaline events in Florida Bay have apparently increased leading to the hypothesis that the recent ecosystem changes in the bay have resulted from changes in salinity (McIvor *et al.*, 1994). Further, it has been hypothesized that salinity variations within the bay are the result of anthropogenic factors, such as diversion of freshwater runoff from the Everglades, freshwater that would otherwise have drained into Florida Bay (McIvor *et al.*, 1994). Hydrologic modeling studies support this hypothesis, showing that

large-scale decreases in freshwater influx to Florida Bay from the Everglades will lead to extreme fluctuations in salinity and an increased occurrence of hypersaline conditions, especially in near-shore sub-basins of central and northeastern Florida Bay (Fennema *et al.*, 1994).

While it is clear from historical accounts that the bay has experienced hypersaline events in the last few decades, very little is known about the long-term salinity history of Florida Bay and whether or not the recent events of hypersalinity are unprecedented prior to human activities in South Florida. Unfortunately, only short and discontinuous instrumental records of Florida Bay salinity have been obtained over the last 50 years, and only anecdotal salinity data exists prior to this time. In place of instrumental data, longer records of Bay salinity have been reconstructed from fossil material deposited and preserved in the bay. For example, on the basis of an oxygen isotopic ($\delta^{18}\text{O}$) record from a Florida Bay coral, Swart *et al.* (1996) postulated that there has been no major long-term increase in salinity in Florida Bay, implying that the events of hypersalinity are part of the natural variability of Florida Bay. They concluded, however, that following construction of the Miami-to-Key West railroad (1905–1910) there was a decrease in the variability of the $\delta^{18}\text{O}$ signal, suggesting a stabilization of salinity conditions in Florida Bay during the period 1905–present relative to 1825–1905. Brewster-Wingard *et al.* (1998) and Brewster-Wingard and Ishman (1999) interpreted molluscan and foraminiferal assemblages from Florida Bay sediment cores to indicate progressively increasing salinity during the later part of the 20th century and an increase in the amplitude of salinity variability about 1940.

The coral record of Swart *et al.* (1996) is from Lignumvitae Basin near the southwestern bay-ocean boundary where seasonal and inter-annual salinity variations are substantially lower than in central Florida Bay. Although they argue that salinity variations in Lignumvitae Basin are representative of salinity changes throughout most of Florida Bay, no comparable studies from interior-basins (where corals are rare) have confirmed this hypothesis. Further, Swart *et al.* (1996) noted the complexity of the coral $\delta^{18}\text{O}$ signal, which is controlled by temperature, rainfall, relative fluxes to the bay of freshwater and seawater, and evaporation, and, consequently, the difficulty in interpreting this record without ambiguity.

In contrast to the coral $\delta^{18}\text{O}$ -based salinity record, paleoecological studies of salinity-dependent fauna and flora from sediment cores suggest multi-decadal scale fluctuations of Florida Bay salinity superimposed on an overall increase in salinity during the last 200

years (Wingard *et al.*, 1995). Like the $\delta^{18}\text{O}$ record, interpreting paleoecological signals may also be complicated by a number of factors, including changes over time in bottom sediment type, temperature, sub-aquatic vegetation, food availability, and predation, leading to uncertainty in paleoecological-based salinity reconstructions.

Here we develop a new geochemical proxy of Florida Bay salinity—the metal/Ca ratios preserved in fossil ostracode shells—and use it to reconstruct the salinity of Florida Bay for the last 180 years. We also compare the paleosalinity record to instrumental rainfall records of South Florida to examine the effects of regional climate variability on Florida Bay salinity.

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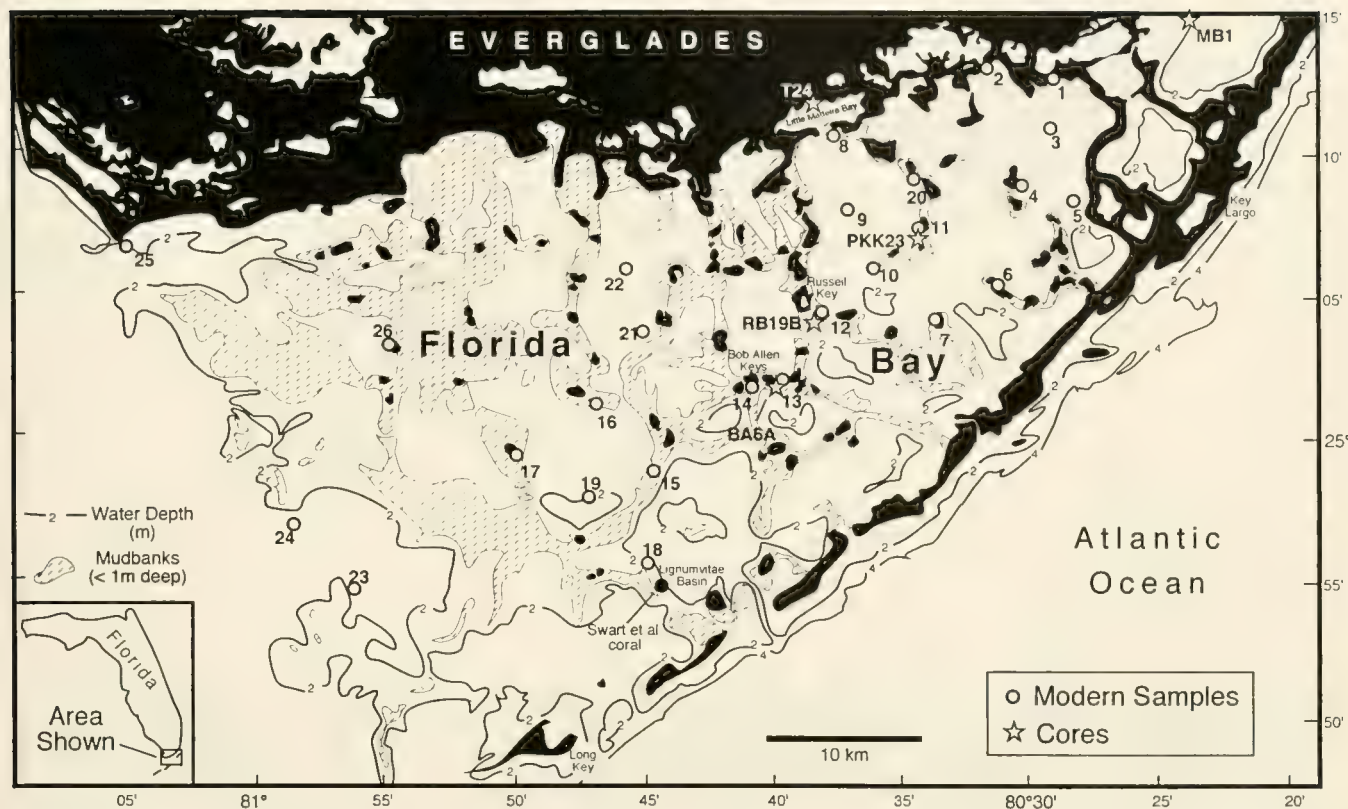
REGIONAL SETTING

Florida Bay (Text-fig. 1) is a triangular-shaped, shallow, restricted marine embayment bounded to the north by the coastal wetlands of the Everglades and to the south by the Florida Keys which separate the bay from open ocean waters of the Straits of Florida. The western boundary of the bay is less distinct, made up of a system of shallow sediment banks that restrict exchange between Florida Bay and the Gulf of Mexico. Water depths range from less than 1 m to about 3 m generally deepening to the south and west (Text-fig. 1). Tidal effects are minimal throughout much of the bay.

Within the bay are a series of sub-basins separated by a network of small islands, called keys, and mudbanks. The mudbanks are submerged, accretionary features and are the primary sites in the bay for the accumulation of sediment, most of which is fine-grained calcium carbonate (mud) derived from calcareous organisms living within the bay (Stockman *et al.*, 1967; Enos and Perkins, 1979).

Waters of Florida Bay are composed primarily of a mixture of two salinity end-members: fresh, terrestrial runoff/discharge from the Everglades with a salinity of less than 1 ppt, and saline, surface waters from the Gulf of Mexico and Straits of Florida with salinity around 36 ppt. Mixing of these two end members leads to a general northeast-to-southwest salinity gradient.

The bay's salinity can also greatly exceed 36 ppt as a result of evaporation. Evaporative concentration of Florida Bay waters generally occurs during the dry season (~November to May) and salinity values ex-



Text-figure 1.—Map showing Florida Bay region and location of sample sites for this study. Also shown is the location of the coral studied by Swart *et al.* (1996).

ceeding 50 ppt have been reported in interior portions of the Bay (Ginsburg, 1972, and see reviews in Swart *et al.*, 1996 and McIvor *et al.*, 1994). Wet season (~May to October) rains bring new runoff from the Everglades and reverse the dry season trend of increasing salinity.

The strong influence of rainfall/runoff on the salinity of Florida Bay is evident from recent monitoring studies and varies in magnitude and timing with distance from the mainland (Text-fig. 2, Text-fig. 3). Shallow groundwater levels in the Everglades, which are largely controlled by rainfall, show a significant correlation with Florida Bay salinity providing further evidence of the impact rainfall/runoff on the salinity of Florida Bay (Tabb, 1967; White, 1983; as reviewed in McIvor *et al.*, 1994).

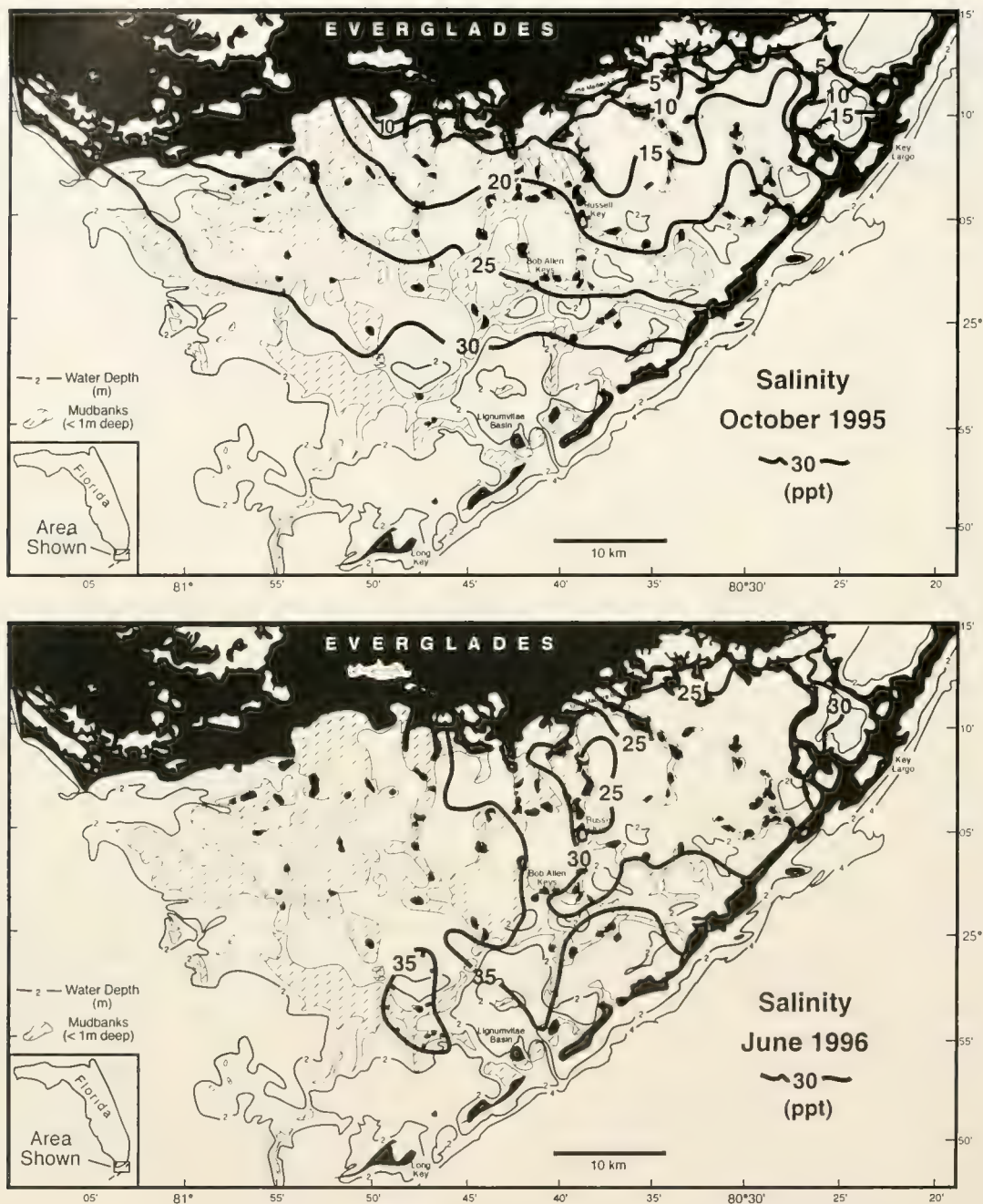
Unfortunately, these studies were conducted after significant modifications were made to the natural runoff system in South Florida, which previously was characterized by sheet flow south from Lake Okeechobee through the Everglades to Florida Bay (Miller, 1997). During this century, a complex network of canals and levees has been constructed in order to control flooding and to drain wetlands for agriculture, ultimately resulting in a lowering of the water table and

an alteration of the near-surface hydrogeology over much of in southern Florida (RAIL, 1973; Miller, 1997). Just after the onset of canal construction around the turn of the century, the Miami to Key West railroad was completed, resulting in partial or complete closing of many of the ocean inlets between the Florida Keys. This has led to the hypothesis that the salinity of Florida Bay may have been markedly different prior to large-scale human activities in south Florida, an idea which we evaluate here by reconstructing the salinity history of central Florida Bay using the chemistry of fossil ostracode shells.

CONTROLS ON OSTRACODE SHELL CHEMISTRY

PREVIOUS STUDIES

Ostracodes are microcrustaceans that inhabit freshwater, brackish, marine, and hypersaline environments. They secrete a bivalved carapace, or shell, that is commonly preserved in sediments and whose chemistry is increasingly being used for paleoenvironmental reconstructions in various aquatic ecosystems (Chivas *et al.*, 1983; Holmes, 1996). The shell is composed mostly of the mineral calcite (CaCO_3), which co-precipitates minor amounts of foreign metals such as magnesium



Text-figure 2.—Examples of salinity distribution in Florida Bay near the end of the wet (October) and dry (June) seasons. Contoured from Halley *et al.* data (1995).

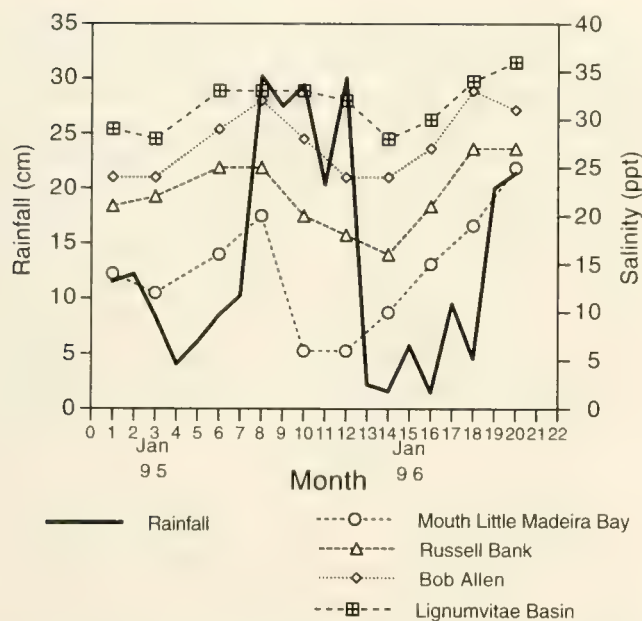
and strontium, that substitute into the crystal lattice in place of calcium. The uptake of Mg or Sr into the calcitic ostracode shell can be described by the following equation:

$$(me/Ca)_{\text{ostracode calcite}} = (K_{D-me})(me/Ca_{\text{water}})$$

where me/Ca represents the atomic ratio of Mg (or Sr) to Ca, and K_{D-me} is the element-specific partition coefficient. Thus, if K_{D-me} is constant or can be con-

strained, then the me/Ca ratio in ostracode calcite can be used to determine the me/Ca ratio of the water in which the shell was secreted (see Wansard, 1996).

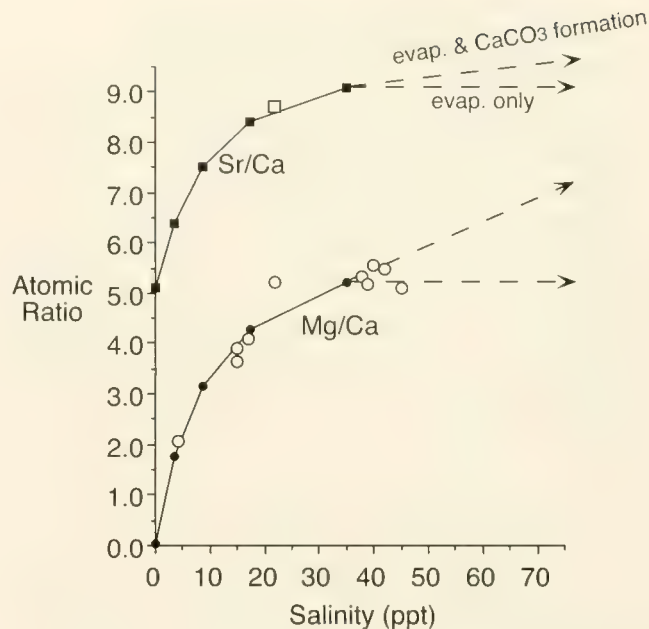
In the waters of Florida Bay, me/Ca ratios appear to vary with salinity as a result of mixing of freshwater runoff and discharge from the Everglades, and sea-water (Text-fig. 4). Thus, $(me/Ca)_{\text{water}}$, as calculated from $(me/Ca)_{\text{ostracode calcite}}$, could be used to estimate Florida Bay salinity.



Text-figure 3.—Time series of monthly rainfall in South Florida (Florida Area 5, NOAA Data Archive) and bi-monthly salinity (Halley *et al.*, 1995) at four locations in Florida Bay for the period from November 1994 to June 1996. Note apparent amplitude decrease and delayed response of salinity change to rainfall with increased distance from mainland.

In addition to $(\text{me}/\text{Ca})_{\text{water}}$, other factors potentially control the uptake of foreign ions into calcite. From experimental and field studies with inorganic and biogenic calcite, $K_{\text{D-Mg}}$ has been shown to have a strong thermodependence (Chave, 1954; Chivas *et al.*, 1983; Cadot and Kaesler, 1977; Burton and Walter, 1991; Dwyer *et al.*, 1995). And $K_{\text{D-Sr}}$ appears to be controlled primarily by calcite precipitation rate (reviewed in Morse and McKenzie, 1990).

Aside from temperature and $\text{Mg}/\text{Ca}_{\text{water}}$, salinity may independently affect $K_{\text{D-Mg}}$. While most workers have concluded that $K_{\text{D-Mg}}$ is constant or increases with increasing salinity, two survey studies of shells of ostracode genus *Cyprideis* from shallow coastal ponds of widely varying salinity (0 to >120 ppt) indicated a negative relationship between $K_{\text{D-Mg}}$ and salinity (Tee-ter and Quick, 1990; Bodergat, 1985). Similarly, Wansard (1996) noted the apparent nonlinearity in $K_{\text{D-Mg}}$ for *Cyprideis* when comparing $K_{\text{D-Mg}}$ calculated for freshwater specimens from Lake Banyoles, Spain (0.0169) to the $K_{\text{D-Mg}}$ calculated for marine specimens by Chivas *et al.* (1986) (0.0045). Unfortunately, results of empirical field studies from sites with significant inter-annual environmental variability often are inconclusive because, even for live specimens, it is difficult to verify that the ostracode shells grew under the environmental conditions measured at the time of collection (*e.g.*, Xia *et al.*, 1997). To avoid the inherent un-



Text-figure 4.—Model data (connected filled symbols) showing the salinity dependence of Mg/Ca (mol/mol) and Sr/Ca (mmol/mol) in waters of Florida Bay. The model assumes conservative mixing of freshwater from the South Florida surficial aquifer system and seawater with the following elemental concentrations (ppm):

	Ca	Mg	Sr	Na
Freshwater (Sonntag, 1987)	90	5.6	0.8	26
Seawater (salinity = 35 ppt, Chester, 1990)	412	1290	7.9	10,770

Open symbols are ratios calculated from Florida Bay water analyses reported by Berner (1966) and Burns and Swart (1992), and they generally agree with the model data. At salinity above normal seawater, me/Ca ratios of Florida Bay waters may behave in a number of ways. Under simple evaporative concentration, ratios will remain unchanged. However, if evaporation concentration is accompanied by significant amounts of CaCO_3 precipitation (biogenic or inorganic), me/Ca ratios of bay waters will continue to increase along with salinity. Relative to Mg/Ca , this effect may be diminished for Sr/Ca because of the relatively high Sr/Ca ratio of aragonite, a mineral that makes up around 60% of the sediments deposited in Florida Bay (Burns and Swart, 1992).

certainties associated with field studies, DeDecker *et al.* (1999) analyzed the chemistry of *Cyprideis* shells raised in laboratory cultures under controlled temperature, salinity, and $\text{Mg}/\text{Ca}_{\text{water}}$ conditions. Their results confirm the strong effects of water temperature and $\text{Mg}/\text{Ca}_{\text{water}}$ on the uptake of Mg and the lack of any salinity effect, positive or negative.

In addition to magnesium and strontium, ostracode shell calcite coprecipitates minor amounts of sodium. However, unlike Mg and Sr, Na is not incorporated in the calcite crystal lattice, but instead resides in crystal defect sites (Busenberg and Plummer, 1985). Evidently sodium uptake is controlled by the sulfate (SO_4^{2-}) concentration of the mother solution (Busenberg and

Plummer, 1985). As a conservative ion in estuarine settings (Chester, 1990), SO_4^{2-} likely covaries with salinity in Florida Bay much like Ca, Mg, Sr, and Na. Therefore, the Na/Ca ratio of ostracode calcite may also be indirectly controlled by salinity and be useful for paleosalinity reconstructions in Florida Bay.

Phylogenetic and ontogenetic factors also influence $K_{\text{D-Mg}}$ and $K_{\text{D-Sr}}$ of ostracode calcite (Chave, 1954; Cadot and Kaesler, 1977; Chivas *et al.*, 1983), requiring the use of shells of same genus and of the same ontogenetic stage for meaningful paleoenvironmental reconstructions based on shell chemistry. Thus it is necessary to calibrate $K_{\text{D-me}}$ for shells of the species selected for paleoenvironmental reconstructions.

STRATEGY TO DEVELOP PALEOSALINITY EQUATIONS

Our strategy was to determine partition coefficients ($K_{\text{D-me}}$) for foreign metals for adult shells of the common species *Loxoconcha matagordensis* on the basis of average me/Ca ratios for Florida Bay water and for average me/Ca ratios in modern specimens of *Loxoconcha matagordensis*. $K_{\text{D-me}}$ would then be used in conjunction with fossil shell me/Ca ratios to calculate past values of $\text{me/Ca}_{\text{water}}$ which in turn would be used to estimate salinity based on the relationship displayed in Text-figure 4.

This modern-average calibration method was preferred over a site-by-site direct calibration of measured salinity to modern shell Mg/Ca at the site (*i.e.*, Dwyer *et al.*, 1995) for three reasons. First, it is difficult to separate the effects of water temperature, which annually varies from about 15–33°C in Florida Bay, from those of salinity. Previous studies, as well as our own data shown below, suggest strong thermodependence of ostracode Mg/Ca ratios. Separating salinity and temperature effects in coastal environments is difficult for most geochemical and faunal proxies of past environmental conditions. However, because temperature and salinity are often positively correlated in Florida Bay waters (Swart *et al.*, 1996; results below), it is quite probable that downcore variability in ostracode shell Mg/Ca is due to changes in both factors (see discussion).

Second, although salinity and temperature were measured at the time of collection of modern *L. matagordensis*, the exact time that each individual ostracode secreted its adult shells was not known. Because adults of *L. matagordensis* live for several months and this species secretes its adult shells year round (King and Kornicker, 1970; Kamiya, 1988), then many adults, in fact, did not secrete their shell at the time of collection. Because salinity and temperature vary temporally and spatially, it is possible only to obtain a

range of possible salinities and temperatures for the site for the previous few months.

Third, during our period of sampling, the mean salinity in the study area varied from ~23.9 ppt (February 1998) to ~33.6 ppt (July 1998). With few exceptions, our material does not include individuals that lived in extremely high (>40 ppt) or low (<18 ppt) salinity environments such as those experienced by Florida Bay historically (Robblee *et al.*, 1991). Consequently, a revised calibration should be developed in the future using individuals grown in cultures at known temperatures, over the widest salinity range possible, which for *L. matagordensis* is 10 to >50 ppt.

METHODOLOGY

ANALYSES OF WATER AND LIVING OSTRACODE SHELLS

Water and ostracode samples for this study were collected from 25 U.S. Geological Survey sites across most of Florida Bay (Text-fig. 1). As part of a larger study to characterize the Florida Bay ecosystem, most of these sites have been sampled seasonally (February and July) since 1994 (Wingard *et al.*, this volume).

Water samples, filtered in the field using disposable 0.45 μm syringe filters, were collected from each of the 25 sites in July 1998 and February 1999. In addition, water samples (unfiltered) were collected in August 1997 from 51 sites in Biscayne Bay and the small bays that lie between Biscayne and Florida Bays. At each site, water temperature and salinity were measured in the field using routinely-calibrated YSI or Hydrolabs brand field instruments (Brewster-Wingard *et al.*, this volume).

Ca, Mg, Sr, and Na concentrations of the water samples were measured by direct current plasma atomic emission spectrophotometry (DCP) in the Plasma Lab at Duke University Earth and Ocean Sciences to determine the relationship between water me/Ca ratios and salinity of south Florida's coastal waters. Final data are reported as Mg/Ca, Sr/Ca, and Na/Ca atomic ratios with analytical precision, based on replicate analysis of IAPSO standard seawater, of $\pm 1\%$, $\pm 2\%$, and $\pm 3\%$, respectively.

Ninety-seven living (whole carapaces with visible soft parts), adult specimens of *Loxoconcha matagordensis*, a cosmopolitan phytal ostracode in Florida Bay (Keyser, 1975; Cronin *et al.*, this volume), were collected from sub-aquatic vegetation from 16 of the 25 USGS sites in Florida Bay in February 1998, July 1998, and February 1999. Shell Mg/Ca, Sr/Ca, and Na/Ca ratios of these specimens were measured by DCP. Procedures follow those in Dwyer *et al.* (1995). An additional step included an overnight soaking of shells in full-strength commercial bleach to remove organic

matter prior to triple rinsing in deionized water. Results are reported as atomic ratios of Mg/Ca, Sr/Ca, and Na/Ca in mmol/mol. Analytical precision, based on replicate analysis of internal-consistency standards is less than $\pm 2\%$ for Mg/Ca and Sr/Ca ratios, and around $\pm 8\%$ for Na/Ca.

From six of the sites we also analyzed the Mg/Ca, Sr/Ca, and Na/Ca ratios of shells of dead adult specimens of *L. matagordensis* collected from the upper 10 cm of sediment push cores. These core-top specimens allowed a comparative evaluation of possible post-mortem alteration effects on shell chemistry.

FOSSIL MATERIAL FROM SEDIMENT CORES

Mg/Ca, Sr/Ca, and Na/Ca ratios were measured on fossil ostracode shells from five 1 to 2 m long sediment cores. Four cores lie along a roughly north-south transect in central Florida Bay (Text-fig. 1). These include mudbank cores BA-6A, RB-19B, and PKK-23 collected in 1994 near Bob Allen, Russell, and Park Keys, respectively, and core T-24 collected from within Little Madeira Bay along the coast of the Everglades near the freshwater outflow region of Taylor Slough. The fifth core, MB-1, is from Manatee Bay in Barnes Sound, an adjacent embayment northeast of Florida Bay.

Chronostratigraphy for the cores was determined by uranium disequilibrium series methods (Wingard *et al.*, 1995; Brewster-Wingard *et al.*, 1997; Robbins *et al.*, in press) and preliminarily corroborated with exotic pollen horizon studies (Wingard *et al.*, 1995). Calculated linear sediment accumulation rates for BA-6A, RB-19B, and PKK-23A are 1.04, 1.22, and 0.78 cm/year, respectively, and were applied to the entire length of the core. Chronostratigraphic information for core T-24 and core MB-1 are still under development.

Samples for ostracode analysis were collected at approximately 2-cm intervals. Most intervals in the 5 cores contained ostracodes and the majority of these yielded adult valves for geochemical analysis. Shells of *Loxoconcha matagordensis* were sufficiently abundant to produce continuous records in the Russell and Park Key cores and the upper half of MB-1. K_{D-me} values for *L. matagordensis* calculated from modern studies were then used to estimate salinity from fossil me/Ca ratios. In cores or intervals with insufficient numbers of *L. matagordensis* in (Bob Allen, T-24, and the lower half of MB-1; Cronin *et al.*, this volume) we analyzed adult shells of second genus, *Peratocytheridea*. However, no K_{D-me} values are available for *Peratocytheridea*, so any down-core trends *Peratocytheridea* me/Ca ratios can only be interpreted qualitatively. Shells were prepared and analyzed for Ca, Mg, Sr, and Na by DCP as for modern specimens discussed above.

RESULTS AND DISCUSSION

WATER CHEMISTRY

The results of water chemistry analysis are listed in Table 1 and summarized in Text-figure 5. As shown in Text-figure 5, Mg/Ca and Sr/Ca ratios of Florida and Biscayne Bay decrease with decreasing salinity, shifting gradually from 35 ppt and 15 ppt and more steeply from 15 ppt to 0 ppt. Na/Ca ratios (not shown) behave similarly.

The trends observed are similar to that predicted from the preliminary water chemistry data presented in Text-figure 4 and the assumption of conservative mixing of Ca, Mg, Sr, and Na between seawater and freshwater runoff from southern peninsular Florida. Mg/Ca values overlap directly with Mg/Ca ratios calculated from the data of Berner (1966) who measured Mg and Ca concentrations at salinity ~5, 17, and 43 ppt in the 1960's.

The steep decrease in me/Ca ratios with salinity is not typical of estuaries of the eastern United States. More typically, estuarine waters show little or no change in Mg/Ca, Sr/Ca, or Na/Ca ratios, retaining seawater-like values well below 15 ppt. This occurs because, relative to South Florida runoff, terrestrial runoff is generally far more depleted in Ca, Mg, Sr, and Na and me/Ca ratios are thus overwhelmed by seawater. The relatively high concentration of these elements, especially Ca, in south Florida runoff is likely the result of interaction between surface water and upper Tertiary carbonate rocks of southern Florida.

Most importantly for this study, the similarities in water chemistry between Florida and Biscayne Bay sampled from 1997 to 1999 and the comparable Mg/Ca ratios obtained by Berner (1966) for Florida Bay suggest that the relationships between me/Ca_{water} and salinity are regionally and temporally persistent.

MODERN SHELL CHEMISTRY

Results of shell chemistry analyses of modern specimens of adult *Loxoconcha matagordensis* from vegetation samples and sediment core tops are listed in Table 2 and the results of vegetation specimens are summarized in Text-figure 6. Text-figure 6 shows shell Mg/Ca and Sr/Ca ratios versus measured ambient water salinity and temperature from sampling trips in February 1998, July 1998 and February 1999.

It is clear from Text-figure 6 that there are no obvious trends between modern shell me/Ca ratios across the entire range of measured water temperature and salinity. Mg/Ca ratios range from 23 to 54 mmol/mol. Shells from February 1999, covering the fewest number of sites in the three seasonal data sets, appear to show a positive correlation with both salinity and tem-

Table 1.—Chemistry of waters from Florida and Biscayne Bays. Calcium, magnesium, strontium, and sodium concentrations reported in ppm; Mg/Ca and Na/Ca as mol/mol, and Sr/Ca as mmol/mol. * Salinity determined using sodium concentration. Florida Bay sites correspond to map (Text-fig. 1). Biscayne Bay sample locations available from the authors.

Sample site	Salinity (ppt)	Ca	Mg	Sr	Na	Mg/Ca	Sr/Ca	Na/Ca
<i>Florida Bay (July 1998)</i>								
1	26.9	332	1005	6	7792	4.99	8.39	40.86
2-Top	23.96	333	972	6	6098	4.81	8.59	31.89
3-Top	29.1	362	1105	7	8303	5.04	8.44	40.02
4	32.45	401	1272	8	9561	5.23	8.61	41.54
5	32.45	400	1249	7	9343	5.15	8.49	40.72
6	35.94	436	1379	8	10657	5.22	8.58	42.63
6-Top	35.31	436	1370	8	10545	5.18	8.53	42.20
7	37.13	457	1431	8	10745	5.17	8.50	41.01
8	23.51	319	914	6	5824	4.72	8.37	31.78
9	28.24	412	1196	8	5831	4.79	8.52	24.67
10	34.63	435	1342	8	9860	5.08	8.48	39.47
11	30.78	380	1192	7	9161	5.17	8.56	41.98
12	36.85	432	1363	8	10523	5.20	8.60	42.42
13	40.12	503	1573	10	11372	5.16	8.67	39.45
14	40.1	498	1538	9	11400	5.09	8.66	39.91
15	36.75	453	1386	8	10512	5.04	8.48	40.42
15-Top	36.18	450	1379	8	10684	5.05	8.61	41.41
16-Top	38.77	432	1327	8	10424	5.07	8.58	42.10
17-Top	34.61	422	1290	8	9573	5.04	8.46	39.52
18	36.74	438	1352	8	10454	5.09	8.56	41.63
20	27.82	349	1054	6	8023	4.97	8.29	40.03
21	39.34	469	1441	9	10946	5.06	8.67	40.66
21-Top	38.72	459	1405	9	10764	5.05	8.54	40.86
22-Top	38.56	469	1455	9	11104	5.11	8.69	41.24
23-Top	36.25	433	1368	8	10639	5.21	8.65	42.84
24	35.93	423	1307	8	10191	5.10	8.51	42.03
24-Top	35.65	431	1337	8	10326	5.12	8.50	41.80
25	35.57	427	1301	8	10126	5.02	8.46	41.31
26-Top	35.18	420	1304	8	10320	5.12	8.63	42.82
<i>Florida Bay (February 1999)</i>								
1	28.16	298	824	6	5704	4.55	8.45	33.32
1	28.16	299	814	5	5384	4.48	8.24	31.34
2	25.24	359	1026	7	6205	4.71	8.35	30.14
3	29.27	385	1145	7	8520	4.90	8.30	38.54
4	27.81	366	1090	7	8281	4.91	8.33	39.43
5	29.35	389	1145	7	8470	4.85	8.22	37.93
6	28.87	374	1111	7	8317	4.90	8.25	38.75
7	30.47	383	1160	7	9021	4.99	8.30	41.02
8	19.38	286	795	5	5003	4.59	8.19	30.51
9	24.06	343	996	6	6141	4.79	8.35	31.23
10	26.86	367	1078	7	6357	4.84	8.38	30.19
11	27.04	358	1058	6	8047	4.88	8.24	39.22
12	28.61	370	1106	7	8362	4.94	8.38	39.45
13	33.17	418	1262	8	9454	4.97	8.21	39.41
14	32.94	422	1287	8	9735	5.03	8.37	40.24
15	34.62	443	1340	8	9880	4.99	8.34	38.87
16	35.34	447	1363	8	10012	5.03	8.50	39.06
17	32.54	427	1308	8	9953	5.05	8.65	40.63
17-banktop*	31.3	417	1262	8	9583	4.99	8.40	40.03
18	35.76	455	1401	9	10250	5.08	8.57	39.31
20	24.97	347	1023	6	6154	4.85	8.53	30.89
21	34.72	440	1313	8	9618	4.92	8.18	38.09
21	34.72	443	1333	8	9633	4.96	8.25	37.91
21-lake*	36.9	543	1646	11	11288	5.00	8.86	36.27
21-lake*	35.4	544	1638	10	10841	4.97	8.70	34.75
22	35.11	427	1302	8	9753	5.03	8.56	39.81
23	34.04	428	1298	8	9707	5.00	8.49	39.54
24	35.13	416	1257	8	9426	4.98	8.37	39.48
26	33.51	409	1223	8	9414	4.93	8.40	40.15
26	33.51	408	1215	7	9201	4.91	8.29	39.34

Table 1.—Continued.

Sample site	Salinity (ppt)	Ca	Mg	Sr	Na	Mg/Ca	Sr/Ca	Na/Ca
<i>Biscayne Bay (August 1997)</i>								
MR06	0.3	64	9	1	3	0.23	4.35	0.07
TM02	0.3	66	8	1	-1	0.20	4.02	-0.04
MR07	0.4	60	11	1	11	0.31	5.71	0.33
MR05	0.5	66	14	1	43	0.34	4.88	1.13
MR04	0.7	71	26	1	172	0.60	5.05	4.23
MR03	1.2	76	39	1	306	0.85	5.20	7.08
WC02	1.4	80	42	1	367	0.87	5.68	8.05
SP01	2.3	88	65	1	562	1.21	4.65	11.10
SK01	2.7	92	94	1	771	1.68	5.72	14.58
MR02	2.8	93	94	1	787	1.67	5.91	14.81
LR03	3.8	96	87	1	723	1.49	5.50	13.11
PR01	5.1	141	172	2	1380	2.01	6.11	17.08
BL02	9.4	174	334	3	2099	3.17	7.24	21.04
AR01	10.9	190	387	3	3020	3.37	7.32	27.76
BL01	12.4	203	469	3	3478	3.80	7.63	29.84
MW01	12.6	198	449	3	3370	3.74	7.59	29.70
GL02	13.4	205	459	3	3408	3.69	7.71	28.94
MR01	16.4	142	279	2	2411	3.24	7.12	29.66
BB51	17.4	233	632	4	4418	4.46	8.19	32.99
BB01	18.2	267	697	5	4658	4.31	8.05	30.45
LR01	19.1	126	209	2	1835	2.74	6.45	25.36
MI01	20.8	269	708	5	5047	4.34	8.01	32.71
CG01	23.3	290	755	5	5253	4.29	8.04	31.54
BB03	23.6	328	918	6	5775	4.61	8.16	30.71
CD01	23.7	319	874	6	5680	4.52	8.14	31.06
BB50	24.1	317	891	6	5798	4.64	8.33	31.90
BB48	26	320	945	6	7464	4.88	8.39	40.71
BB48	26	317	938	6	7537	4.88	8.46	41.49
BB09	26.4	314	919	6	7353	4.82	8.32	40.82
BB39A	26.9	346	1029	6	7903	4.91	8.37	39.87
BB34	29	327	964	6	7562	4.86	8.29	40.29
BB47	30.2	366	1110	7	8686	5.00	8.41	41.39
BB10	31.1	384	1166	7	8912	5.00	8.35	40.41
BB27	31.7	386	1174	7	9009	5.02	8.48	40.68
BB5A	31.9	398	1220	7	9292	5.06	8.46	40.75
BB23	32	383	1165	7	9009	5.01	8.51	40.98
BB29	32.1	392	1191	7	9114	5.01	8.47	40.55
BB31	32.4	393	1206	7	9233	5.06	8.57	41.01
BB28	32.6	394	1200	7	9122	5.03	8.39	40.38
BB44	32.9	397	1219	7	9338	5.06	8.54	40.99
BB41	33	390	1210	7	9274	5.12	8.59	41.48
BB45	33.1	400	1220	7	9240	5.04	8.41	40.31
BB45	33.1	393	1218	7	9362	5.11	8.57	41.51
BB32	33.8	372	1151	7	8917	5.10	8.53	41.78
NNH	33.9	412	1273	8	9538	5.10	8.53	40.41
BB25	35.2	413	1283	8	10087	5.13	8.47	42.60
BB46	35.2	416	1305	8	10320	5.18	8.62	43.29
BB07	35.6	427	1330	8	10513	5.14	8.62	42.94
BB35	35.8	420	1322	8	10265	5.18	8.59	42.56
BB42	36.1	428	1353	8	10615	5.22	8.78	43.28
BB36	36.4	430	1335	8	10174	5.12	8.41	41.25
BB43	36.7	433	1354	8	10474	5.15	8.40	42.16
BB37	37.3	436	1374	8	10707	5.19	8.67	42.81
BB39*	33.9	425	1329	8	10377	5.16	8.63	42.57
<i>Standards*</i>								
IAPSO	33.4	422	1314	8	10235	5.14	8.28	42.29
IAPSO	33.0	424	1310	8	10093	5.10	8.14	41.54
IAPSO	32.7	432	1328	8	10015	5.07	8.33	40.43
IAPSO	35.1	430	1334	8	10740	5.12	8.57	43.57
IAPSO	33.5	440	1345	8	10247	5.05	8.38	40.64
IAPSO	32.9	436	1349	8	10077	5.10	8.38	40.26

Table 2.—Chemistry of living and sediment coretop shells of adult specimens of *Loxoconcha matagordensis*. Mg/Ca, Sr/Ca, and Na/Ca ratios reported as mmol/mol. * Salinity determined using sodium concentration. Florida Bay sites correspond to map (Text-fig. 1). Sample descriptors (e.g. #1, A) refer to separate subsamples from the sites. Biscayne Bay sample BB51 is located near the MBI core site (Text-fig. 1). VPI (visual preservation index) is a measure of shell clarity ranging from 1 (clear, unaltered) to 7 (opaque, highly altered).

Sample Site	Temp. (°C)	Salinity (ppt)	VPI	Mg/Ca	Sr/Ca	Na/Ca
Florida Bay Living Specimens						
<i>February 1998</i>						
17	25.9	31.7	4	29.13	3.47	14.18
17	25.9	31.7	4	26.06	3.39	12.21
17	25.9	31.7	4	35.64	3.46	15.41
17	25.9	31.7	4	37.78	3.65	15.04
17	25.9	31.7	4	29.20	3.34	13.77
17	25.9	31.7	4	43.08	3.70	17.56
1	21	15.8	4	37.70	3.79	15.70
1	21	15.8	4	36.59	3.57	16.03
1	21	15.8	3	38.64	3.86	15.85
1	21	15.8	2	46.84	3.29	17.03
1#1	21	15.8	2.5	37.14	3.98	16.78
1#1	21	15.8	2.5	27.01	4.18	14.53
1#1	21	15.8	2.5	28.18	3.60	18.45
4#4	21.6	16.7	2.5	29.85	3.81	26.86
4#4	21.6	16.7	2.5	35.58	4.10	16.43
5#5	21.9	17.6	2.5	40.34	3.68	14.57
5#5	21.9	17.6	2.5	39.68	4.05	15.44
5#5	21.9	17.6	2.5	26.70	4.19	13.95
8#1	20	15.2	2.5	26.50	4.10	13.67
8#1	20	15.2	2.5	25.59	4.01	11.88
8#1	20	15.2	2.5	30.56	4.23	14.78
11#5	19.4	19.3	2.5	37.53	3.69	15.44
11#5	19.4	19.3	2.5	44.98	3.99	13.96
11#5	19.4	19.3	2.5	35.34	3.86	16.02
12#2	21.6	20.7	2.5	29.20	3.93	16.55
12#2	21.6	20.7	2.5	25.94	3.78	14.04
14#1	23.8	26.9	2.5	29.85	3.76	15.56
14#1	23.8	26.9	2.5	27.73	3.53	16.77
16#1	26.3	30.1	2.5	28.17	3.91	15.74
16#1	26.3	30.1	2.5	28.81	3.93	18.28
16#1	26.3	30.1	2.5	26.42	3.58	14.84
17#3	25.9	31.7	2.5	24.46	3.67	14.87
17#3	25.9	31.7	2.5	30.07	3.59	16.97
18#2	24.9	29.7	2.5	26.12	3.64	15.24
18#2	24.9	29.7	2.5	29.74	3.76	16.13
20#1	19.9	17.1	2.5	25.33	4.01	14.61
20#1	19.9	17.1	2.5	31.13	4.01	15.61
20#1	19.9	17.1	2.5	29.91	3.86	14.23
21 Shell	24	28.9	2.5	29.53	4.02	15.79
21 Shell	24	28.9	2.5	29.02	3.70	15.36
21 Shell	24	28.9	2.5	29.93	3.70	14.06
22#1	24.9	30.2	2.5	23.41	3.70	12.31
22#1	24.9	30.2	2.5	22.53	3.91	13.93
22#1	24.9	30.2	2.5	30.89	3.54	14.83
23#1	23.5	33	2.5	26.94	3.53	15.56
26#1	27.6	31.6	2.5	36.37	3.70	14.94
26#1	27.6	31.6	2.5	34.11	3.45	14.50

Table 2.—Continued.

Sample Site	Temp. (°C)	Salinity (ppt)	VPI	Mg/Ca	Sr/Ca	Na/Ca
<i>July 1998</i>						
17#1	28.42	36.25	2.5	40.70	4.05	14.71
1A#3	31.3	26.9	2.5	39.71	4.31	17.09
1A#3	31.3	26.9	2.5	35.88	3.96	13.99
23#1	31.94	36.76	2.5	44.49	3.68	17.00
22#1	30.42	39.93	2.5	36.11	4.20	14.34
22#1	30.42	39.93	2.5	42.48	4.27	15.17
8A#2	30.86	23.88	2.5	38.22	3.97	16.45
8A#2	30.86	23.88	2.5	43.36	4.16	14.66
16#2	29.38	38.73	2.5	37.85	4.01	21.72
16#2	29.38	38.73	2.5	32.71	3.77	17.22
11A#2	32.99	33.13	2.5	39.95	3.83	14.00
11A#2	32.99	33.13	2.5	35.85	3.92	13.38
11A#2	32.99	33.13	2.5	41.72	3.75	16.57
5A#2	33.42	31.94	2.5	39.79	3.55	15.46
12A#2	34.58	36.97	2.5	38.14	3.83	16.53
12A#2	34.58	36.97	2.5	35.41	4.02	14.87
18#1	29.25	37.15	2.5	37.98	3.89	14.65
18#1	29.25	37.15	2.5	44.97	3.84	18.69
18#1	29.25	37.15	2.5	43.09	3.65	16.34
20A#3	32.02	28.15	2.5	35.31	4.23	16.91
20A#3	32.02	28.15	2.5	38.60	4.62	18.97
26#2	33.26	35.43	2.5	32.89	3.72	17.12
26#2	33.26	35.43	2.5	34.51	3.33	16.87
26#2	33.26	35.43	2.5	35.40	3.41	16.32
6A	33.29	35.94	2.5	39.06	3.97	16.24
6A	33.29	35.94	2.5	41.54	3.93	15.68
6A	33.29	35.94	2.5	42.19	4.03	15.23
4A#1	32.88	32.15	2.5	38.18	3.90	14.24
4A#1	32.88	32.15	2.5	45.04	3.84	16.89
4A#1	32.88	32.15	2.5	42.49	3.79	14.55
14#1	33.01	41.03	2.5	30.04	3.69	17.62
14#1	33.01	41.03	2.5	29.70	3.90	18.85
14#1	33.01	41.03	2.5	34.29	4.23	14.39
22	30.4	39.9	3	38.82	4.00	16.63
22	30.4	39.9	3	35.30	4.18	16.90
22	30.4	39.9	5	37.46	4.32	27.50
8	30.9	23.9	4	44.42	3.86	13.72
8	30.9	23.9	4	37.95	4.47	16.25
8	30.9	23.9	1	50.39	4.02	16.04
8	30.9	23.9	4	41.77	4.11	14.16
8	30.9	23.9	4	44.62	3.75	12.76
<i>February 1999</i>						
18	22.6	35.8	3	44.99	3.32	15.30
18	22.6	35.8	3	33.53	3.45	15.60
18	22.6	35.8	3	46.06	3.75	17.42
18	22.6	35.8	3	38.74	3.74	16.33
18	22.6	35.8	3	53.83	3.36	14.16
8	20	19.4	3	31.73	4.35	15.87
8	20	19.4	3	37.92	4.03	18.78
8	20	19.4	3	38.77	4.05	15.60
8	20	19.4	2	37.34	4.42	15.65
8	20	19.4	3	33.99	4.25	15.35

Table 2.—Continued.

Sample Site	Temp. (°C)	Salinity (ppt)	VPI	Mg/Ca	Sr/Ca	Na/Ca
Coretop Specimens						
<i>Florida Bay (July 1998)</i>						
22	30.42	39.93	2.5	35.87	3.85	16.27
22	30.42	39.93	2.5	36.09	3.58	18.30
26	33.26	35.43	2.5	33.85	3.90	15.77
26	33.26	35.43	2.5	39.68	3.61	14.73
26	33.26	35.43	2.5	35.75	3.76	16.99
26	33.26	35.43	2.5	34.83	3.73	15.50
21	30.34	39.34	2.5	35.93	3.96	17.47
21	30.34	39.34	2.5	24.22	3.69	15.52
21	30.34	39.34	2.5	30.81	3.66	15.40
21	30.34	39.34	2.5	39.53	4.13	16.69
23	31.94	36.76	2.5	34.42	3.95	15.97
23	31.94	36.76	2.5	37.62	3.84	16.73
1B	31.3	26.9	2.5	40.72	3.85	16.13
1B	31.3	26.9	2.5	42.00	3.77	17.44
1B	31.3	26.9	2.5	36.14	3.69	15.89
1B	31.3	26.9	2.5	37.58	3.69	14.73
1B	31.3	26.9	2.5	42.42	3.80	17.89
1B	31.3	26.9	2.5	33.82	3.76	14.98
1B	31.3	26.9	2.5	33.10	3.81	16.75
1B	31.3	26.9	2.5	38.18	3.67	15.50
1B	31.3	26.9	2.5	30.27	3.21	15.15
1B	31.3	26.9	2.5	49.81	4.14	13.99
1B	31.3	26.9	2.5	46.15	4.02	16.34
1B	31.3	26.9	2.5	41.46	3.71	14.84
20A	32.02	28.15	2.5	36.25	3.75	15.06
9	31.32	28.8	2.5	37.35	3.46	16.03
9	31.32	28.8	2.5	52.15	3.31	11.09
9	31.32	28.8	2.5	48.07	4.02	15.59
9	31.32	28.8	2.5	39.17	3.52	15.57
9	31.32	28.8	2.5	42.45	4.28	14.08
9	31.32	28.8	2.5	40.73	3.68	14.37
15	28.54	36.75	2.5	48.59	3.38	14.35
15	28.54	36.75	2.5	50.19	3.76	14.20
15	28.54	36.75	2.5	46.59	3.80	17.16
15	28.54	36.75	2.5	34.57	3.83	17.11
15	28.54	36.75	2.5	36.45	4.11	17.40
22	30.42	39.93	2.5	36.07	3.77	16.75
22	30.42	39.93	2.5	36.67	3.86	14.84
26	33.26	35.43	2.5	51.86	2.90	12.46
26	33.26	35.43	2.5	44.47	3.24	15.40
26	33.26	35.43	2.5	34.52	3.39	15.53
26	33.26	35.43	2.5	32.05	3.74	14.71
26	33.26	35.43	2.5	43.11	3.59	15.46
21	30.34	39.34	2.5	43.41	3.71	16.24
21	30.34	39.34	2.5	36.39	3.26	16.21
21	30.34	39.34	2.5	39.86	3.75	13.33
23	31.94	36.76	2.5	43.07	4.04	17.16
23	31.94	36.76	2.5	39.89	3.75	15.58
23	31.94	36.76	2.5	39.55	3.98	17.76
23	31.94	36.76	2.5	36.94	3.57	15.11
1B	31.3	26.9	2.5	44.04	4.06	17.16
1B	31.3	26.9	2.5	45.40	3.39	16.51
1B	31.3	26.9	2.5	39.83	3.70	16.01
1B	31.3	26.9	2.5	34.23	3.51	13.89
1B	31.3	26.9	2.5	33.38	4.17	13.38
1B	31.3	26.9	2.5	42.95	3.96	14.50
20A	32.02	28.15	2.5	36.22	3.37	15.86
20A	32.02	28.15	2.5	42.39	4.12	15.89
20A	32.02	28.15	2.5	46.61	3.69	15.99

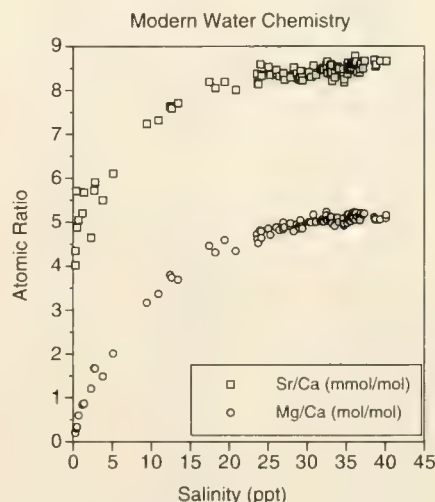
Table 2.—Continued.

Sample Site	Temp. (°C)	Salinity (ppt)	VPI	Mg/Ca	Sr/Ca	Na/Ca
9	31.32	28.8	2.5	48.09	3.89	13.58
9	31.32	28.8	2.5	38.72	3.89	16.57
9	31.32	28.8	2.5	38.89	4.01	13.27
9	31.32	28.8	2.5	28.74	3.90	15.20
9	31.32	28.8	2.5	37.77	3.53	14.71
15	28.54	36.75	2	40.00	3.71	16.54
<i>Biscayne Bay (August 1997)</i>						
BB51	31.35	17.4	3	33.14	3.64	16.39
BB51	31.35	17.4	3	30.81	3.73	17.43
BB51	31.35	17.4	3	37.59	4.11	15.76
BB51	31.35	17.4	4	42.50	3.91	14.98
BB51	31.35	17.4	3	32.50	3.46	15.52
BB51	31.35	17.4	2	31.02	3.55	16.47
BB51	31.35	17.4	3	40.05	3.64	16.55
BB51	31.35	17.4	2	41.04	3.83	17.35

perature. There also seems to be broad positive correlation between Mg/Ca and temperature. Furthermore, shells collected from July 1998, when both salinity and temperature were relatively high, all have Mg/Ca ratios $> \sim 30$ mmol/mol.

Sr/Ca ratios range from 3.3 to 4.6 mmol/mol and appear to display a broad negative correlation with both salinity and temperature, especially within the February data. Na/Ca ratios (not shown) range from 12 to 19 mmol/mol and show no variation with salinity or temperature.

Core-top specimens (Table 2), consisting of both articulated and disarticulated valves, yield Mg/Ca, Sr/Ca, and Na/Ca ratios that are indistinguishable from those of vegetation samples. This implies that post-mortem effects on shell me/Ca ratios in Florida Bay are neg-



Text-figure 5.—Mg/Ca and Sr/Ca ratios of waters from Florida and Biscayne Bays collected in 1997–99.

Table 3.—Chemistry of fossil shells of *Loxochoncha matagordensis* and *Peratocytheridea setipunctata* from downcore portions of sediment cores from Florida Bay. Core numbers correspond to map (Text-fig. 1). Mg/Ca, Sr/Ca, and Na/Ca ratios reported as mmol/mol. Intra-sample average ratios reported in right three columns. Most shells analyzed were adult stage, though some juvenile molts were also analyzed. VPI (visual preservation index) is a measure of shell clarity ranging from 1 (clear, unaltered) to 7 (opaque, highly altered).

Depth (cm)	Year	Genus	Species	Molt	VPI	Mg/Ca	Sr/Ca	Na/Ca	Mg/Ca (avg.)	Sr/Ca (avg.)	Na/Ca (avg.)
<i>Russell Bank Core 19B</i>											
Site 12*	1998.0	<i>L.</i>	<i>matagord.</i>	A	2.5	29.20	3.93	16.55	32.17	3.89	15.50
Site 12*	1998.0	<i>L.</i>	<i>matagord.</i>	A	2.5	25.94	3.78	14.04			
Site 12*	1998.0	<i>L.</i>	<i>matagord.</i>	A	2.5	38.14	3.83	16.53			
Site 12*	1998.0	<i>L.</i>	<i>matagord.</i>	A	2.5	35.41	4.02	14.87			
1	1994.2	<i>L.</i>	<i>matagord.</i>	A	1	40.57	4.07	16.60	37.84	4.03	16.25
1	1994.2	<i>L.</i>	<i>matagord.</i>	A	2	37.07	4.17	16.81			
1	1994.2	<i>L.</i>	<i>matagord.</i>	A	1	35.89	3.85	15.34			
3	1992.5	<i>L.</i>	<i>matagord.</i>	A	3	39.82	4.08	15.67	38.39	3.95	16.88
3	1992.5	<i>L.</i>	<i>matagord.</i>	A	3	36.97	3.81	18.10			
5	1990.9	<i>L.</i>	<i>matagord.</i>	A	3	40.19	3.44	16.04	39.46	3.78	15.64
5	1990.9	<i>L.</i>	<i>matagord.</i>	A	2	36.97	3.98	16.23			
5	1990.9	<i>L.</i>	<i>matagord.</i>	A	1	41.22	3.93	14.66			
7	1989.3	<i>L.</i>	<i>matagord.</i>	A	3	36.87	3.90	15.27	39.61	3.94	15.67
7	1989.3	<i>L.</i>	<i>matagord.</i>	A	3	42.35	3.98	16.07			
9	1987.6	<i>L.</i>	<i>matagord.</i>	A	2	32.10	3.60	16.63	36.08	3.74	15.95
9	1987.6	<i>L.</i>	<i>matagord.</i>	A	4	36.94	3.56	15.48			
9	1987.6	<i>L.</i>	<i>matagord.</i>	A	4	39.19	4.06	15.74			
11	1986.0	<i>L.</i>	<i>matagord.</i>	A	2	31.43	4.18	17.40	32.48	4.09	16.50
11	1986.0	<i>L.</i>	<i>matagord.</i>	A	3	31.39	3.72	16.68			
11	1986.0	<i>L.</i>	<i>matagord.</i>	A	4	34.61	4.37	15.42			
13	1984.3	<i>L.</i>	<i>matagord.</i>	A	2	29.87	3.83	18.11	34.92	3.78	16.09
13	1984.3	<i>L.</i>	<i>matagord.</i>	A	4	36.75	3.68	15.44			
13	1984.3	<i>L.</i>	<i>matagord.</i>	A	4	38.14	3.84	14.71			
15	1982.7	<i>L.</i>	<i>matagord.</i>	A	4	41.81	3.97	13.13	35.10	3.91	14.79
15	1982.7	<i>L.</i>	<i>matagord.</i>	A	2	33.30	3.75	15.58			
15	1982.7	<i>L.</i>	<i>matagord.</i>	A	3	30.17	4.01	15.65			
17	1981.1	<i>L.</i>	<i>matagord.</i>	A	4	31.30	3.73	13.99	34.99	3.56	14.97
17	1981.1	<i>L.</i>	<i>matagord.</i>	A	4	39.24	3.18	15.58			
17	1981.1	<i>L.</i>	<i>matagord.</i>	A	3	34.42	3.76	15.33			
19	1979.4	<i>L.</i>	<i>matagord.</i>	A	2	35.40	3.79	15.73	40.09	3.64	15.12
19	1979.4	<i>L.</i>	<i>matagord.</i>	A	4	44.78	3.50	14.50			
21	1977.8	<i>L.</i>	<i>matagord.</i>	A	3	36.75	4.27	18.29	36.75	4.27	18.29
23	1976.1	<i>L.</i>	<i>matagord.</i>	A	3	32.97	3.68	16.25	38.00	3.51	15.14
23	1976.1	<i>L.</i>	<i>matagord.</i>	A	3	43.43	3.36	15.78			
23	1976.1	<i>L.</i>	<i>matagord.</i>	A	3	37.60	3.51	13.40			
25	1974.5	<i>L.</i>	<i>matagord.</i>	A	3	37.30	3.85	13.09	36.02	3.74	14.76
25	1974.5	<i>L.</i>	<i>matagord.</i>	A	3	35.18	3.60	15.08			
25	1974.5	<i>L.</i>	<i>matagord.</i>	A	3	35.59	3.75	16.12			
27	1972.9	<i>L.</i>	<i>matagord.</i>	A	3	36.44	3.95	16.60	36.67	3.68	15.13
27	1972.9	<i>L.</i>	<i>matagord.</i>	A	3	31.25	3.60	16.36			
27	1972.9	<i>L.</i>	<i>matagord.</i>	A	3	42.33	3.50	12.42			
29	1971.2	<i>L.</i>	<i>matagord.</i>	A	3	30.07	3.55	16.42	31.95	3.78	16.92
29	1971.2	<i>L.</i>	<i>matagord.</i>	A	3	33.82	4.02	17.42			
31	1969.6	<i>L.</i>	<i>matagord.</i>	A	3	28.06	3.52	17.19	37.85	3.78	15.53
31	1969.6	<i>L.</i>	<i>matagord.</i>	A	4	42.47	4.13	14.05			
31	1969.6	<i>L.</i>	<i>matagord.</i>	A	3	43.01	3.68	15.36			
33	1968.0	<i>L.</i>	<i>matagord.</i>	A	4	33.07	3.88	15.93	36.21	4.09	15.39
33	1968.0	<i>L.</i>	<i>matagord.</i>	A	3	39.89	4.24	15.71	39.59	3.78	15.11
33	1968.0	<i>L.</i>	<i>matagord.</i>	A	2	35.68	4.13	14.53			
35	1966.3	<i>L.</i>	<i>matagord.</i>	A	3	41.36	4.06	15.71			
35	1966.3	<i>L.</i>	<i>matagord.</i>	A	3	41.07	3.52	15.71	41.37	4.03	15.63
35	1966.3	<i>L.</i>	<i>matagord.</i>	A	3	36.34	3.77	13.92			
37	1964.7	<i>L.</i>	<i>matagord.</i>	A	3	39.80	4.01	15.87	46.37	3.92	15.11
37	1964.7	<i>L.</i>	<i>matagord.</i>	A	3	42.94	4.05	15.38			
39	1963.0	<i>L.</i>	<i>matagord.</i>	A	3	48.80	4.05	12.16			
39	1963.0	<i>L.</i>	<i>matagord.</i>	A	3	46.63	3.74	15.77	41.16	4.09	15.29

Table 3.—Continued.

Depth (cm)	Year	Genus	Species	Molt	VPI	Mg/Ca	Sr/Ca	Na/Ca	Mg/Ca (avg.)	Sr/Ca (avg.)	Na/Ca (avg.)
39	1963.0	L.	matagord.	A	4	43.68	3.97	17.39			
41	1961.4	L.	matagord.	A	2	41.97	3.94	17.50			
41	1961.4	L.	matagord.	A	3	40.36	4.25	13.08			
43	1959.8	L.	matagord.	A	3	33.40	4.17	15.75	41.29	3.92	16.19
43	1959.8	L.	matagord.	A	—	49.18	3.66	16.63			
45	1958.1	L.	matagord.	A	3	35.52	3.82	14.83	35.52	3.82	14.83
47	1956.5	L.	matagord.	A	3	39.51	3.27	17.12	42.27	3.77	15.51
47	1956.5	L.	matagord.	A	3	48.59	4.00	13.49			
47	1956.5	L.	matagord.	A	3	38.70	4.02	15.93			
49	1954.8	L.	matagord.	A	3	36.08	3.93	15.54	42.15	3.81	14.81
49	1954.8	L.	matagord.	A	3	46.31	3.44	14.75			
49	1954.8	L.	matagord.	A	3	44.06	4.04	14.15			
51	1953.2	L.	matagord.	A	3	28.07	3.65	17.61	33.74	3.90	15.53
51	1953.2	L.	matagord.	A	4	28.57	3.98	13.90			
51	1953.2	L.	matagord.	A	3	44.57	4.05	15.09			
53	1951.6	L.	matagord.	A	3	31.80	3.48	15.48	37.71	3.80	14.54
53	1951.6	L.	matagord.	A	3	40.79	4.20	14.00			
53	1951.6	L.	matagord.	A	3	40.54	3.73	14.15			
55	1949.9	L.	matagord.	A	3.5	36.35	3.88	13.88	35.38	3.86	14.96
55	1949.9	L.	matagord.	A	3.5	35.20	3.92	16.28			
55	1949.9	L.	matagord.	A	3.5	34.60	3.77	14.73			
57	1948.3	L.	matagord.	A	3.5	42.42	4.05	13.05	37.10	3.98	15.25
57	1948.3	L.	matagord.	A	3.5	31.49	3.80	14.80			
57	1948.3	L.	matagord.	A	3.5	37.39	4.09	17.92			
59	1946.6	L.	matagord.	A	3.5	44.98	3.33	14.41	41.53	3.65	15.12
59	1946.6	L.	matagord.	A	3.5	36.70	3.88	16.87			
59	1946.6	L.	matagord.	A	3.5	42.90	3.76	14.08			
61	1945.0	L.	matagord.	A	3.5	34.42	3.89	13.72	41.67	3.57	14.99
61	1945.0	L.	matagord.	A	3.5	48.91	3.25	16.26			
63	1943.4	L.	matagord.	A	3.5	33.84	3.72	18.16	32.01	3.86	16.41
63	1943.4	L.	matagord.	A	3.5	26.60	3.93	15.67			
63	1943.4	L.	matagord.	A	3.5	35.59	3.93	15.39			
65	1941.7	L.	matagord.	A	3.5	42.19	4.19	15.56	35.44	3.70	15.63
65	1941.7	L.	matagord.	A	3.5	25.77	3.22	15.40			
65	1941.7	L.	matagord.	A	3.5	38.35	3.68	15.92			
67	1940.1	L.	matagord.	A	3.5	26.85	3.75	14.89	33.16	3.91	15.45
67	1940.1	L.	matagord.	A	3.5	39.48	4.08	16.00			
69	1938.4	L.	matagord.	A	3.5	31.24	3.94	16.06	38.52	3.62	15.15
69	1938.4	L.	matagord.	A	3.5	36.77	3.60	17.20			
69	1938.4	L.	matagord.	A	3.5	47.54	3.31	12.18			
71	1936.8	L.	matagord.	A	3.5	35.45	3.94	20.43	32.76	4.06	17.27
71	1936.8	L.	matagord.	A	3.5	32.04	4.15	14.21			
71	1936.8	L.	matagord.	A	3.5	33.75	4.25	17.10			
71	1936.8	L.	matagord.	A	3.5	29.80	3.89	17.35			
73	1935.2	L.	matagord.	A	3.5	43.92	3.77	15.55	39.82	3.74	15.44
73	1935.2	L.	matagord.	A	3.5	29.10	3.94	18.92			
73	1935.2	L.	matagord.	A	3.5	46.43	3.50	11.85			
75	1933.5	L.	matagord.	A	3.5	33.46	3.66	13.69	34.40	3.57	14.66
75	1933.5	L.	matagord.	A	3.5	33.55	3.39	15.08			
75	1933.5	L.	matagord.	A	3.5	36.18	3.67	15.22			
77	1931.9	L.	matagord.	A	3.5	34.49	4.19	16.18	39.61	3.97	14.41
77	1931.9	L.	matagord.	A	3.5	44.74	3.75	12.64			
79	1930.2	L.	matagord.	A	3.5	36.38	3.85	14.29	38.18	3.85	15.18
79	1930.2	L.	matagord.	A	3.5	29.62	3.81	15.96			
79	1930.2	L.	matagord.	A	3.5	48.54	3.89	15.30			
81	1928.6	L.	matagord.	A	3.5	32.32	4.21	15.21	39.08	3.85	14.61
81	1928.6	L.	matagord.	A	3.5	42.56	3.57	14.32			
81	1928.6	L.	matagord.	A	3.5	42.35	3.77	14.30			
83	1927.0	L.	matagord.	A	3.5	32.54	3.91	14.71	35.98	3.96	15.62
83	1927.0	L.	matagord.	A	3.5	42.88	3.98	16.96			

Table 3.—Continued.

Depth (cm)	Year	Genus	Species	Molt	VPI	Mg/Ca	Sr/Ca	Na/Ca	Mg/Ca (avg.)	Sr/Ca (avg.)	Na/Ca (avg.)
83	1927.0	L.	matagord.	A	3.5	32.53	4.00	15.20			
85	1925.3	L.	matagord.	A	3.5	34.11	3.47	17.69	32.88	3.73	15.55
85	1925.3	L.	matagord.	A	3.5	31.65	3.99	13.42			
87	1923.7	L.	matagord.	A	3.5	33.59	3.83	16.18	39.36	3.70	16.40
87	1923.7	L.	matagord.	A	3.5	41.05	3.80	17.83			
87	1923.7	L.	matagord.	A	3.5	43.44	3.47	15.19			
89	1922.0	L.	matagord.	A	3.5	37.86	4.20	14.07	35.43	4.12	14.22
89	1922.0	L.	matagord.	A	3.5	34.23	4.05	14.43			
89	1922.0	L.	matagord.	A	3.5	34.21	4.12	14.16			
93	1918.8	L.	matagord.	A	3.5	34.39	3.84	15.34	38.23	3.67	15.30
93	1918.8	L.	matagord.	A	3.5	52.25	3.40	15.10			
93	1918.8	L.	matagord.	A	3.5	28.03	3.77	15.48			
95	1917.1	L.	matagord.	A	3.5	32.87	4.12	14.68	32.87	4.12	14.68
97	1915.5	L.	matagord.	A	3.5	28.97	3.60	14.84	28.97	3.60	14.84
99	1913.9	L.	matagord.	A	3.5	32.60	3.98	16.64	32.60	3.98	16.64
101	1912.2	L.	matagord.	A	3.5	36.37	3.59	15.51	36.37	3.59	15.51
103	1910.6	L.	matagord.	A	3.5	36.49	3.65	14.09	33.22	3.68	13.85
103	1910.6	L.	matagord.	A	3.5	32.29	3.79	13.60			
103	1910.6	L.	matagord.	A	3.5	30.87	3.60	13.84			
105	1908.9	L.	matagord.	A	3.5	32.82	3.98	13.66	37.66	3.84	15.23
105	1908.9	L.	matagord.	A	3.5	45.68	3.70	16.77			
105	1908.9	L.	matagord.	A	3.5	34.47	3.84	15.25			
107	1907.3	L.	matagord.	A	3.5	31.31	4.03	16.13	36.32	4.11	15.14
107	1907.3	L.	matagord.	A	3.5	41.34	4.20	14.15			
109	1905.7	L.	matagord.	A	3.5	36.09	3.76	16.67	33.07	3.73	16.11
109	1905.7	L.	matagord.	A	3.5	35.36	3.80	17.91			
109	1905.7	L.	matagord.	A	3.5	27.76	3.64	13.76			
113	1902.4	L.	matagord.	A	3.5	32.15	3.66	13.96	32.33	3.67	14.69
113	1902.4	L.	matagord.	A	3.5	32.52	3.68	15.43			
115	1900.7	L.	matagord.	A	3.5	32.88	3.88	17.37	32.88	3.88	17.37
119	1897.5	L.	matagord.	A	3.5	48.35	3.43	15.21	48.35	3.43	15.21
121	1895.8	L.	matagord.	A	3.5	33.64	3.64	15.28	33.64	3.64	15.28
123	1894.2	L.	matagord.	A	3.5	37.04	3.84	15.89			
123	1894.2	L.	matagord.	A	3.5	35.54	3.60	15.10			
125	1892.5	L.	matagord.	A	3.5	36.19	4.05	13.33	35.35	3.80	16.59
125	1892.5	L.	matagord.	A	3.5	32.70	4.08	22.80			
125	1892.5	L.	matagord.	A	3.5	37.16	3.26	13.63			
129	1889.3	L.	matagord.	A	3.5	38.87	3.52	15.02	33.40	3.70	15.61
129	1889.3	L.	matagord.	A	3.5	29.21	3.84	15.13			
129	1889.3	L.	matagord.	A	3.5	32.13	3.74	16.69			
131	1887.6	L.	matagord.	A	3.5	34.92	3.82	18.10	37.87	3.86	18.63
131	1887.6	L.	matagord.	A	3.5	40.82	3.90	19.15			
137	1882.7	L.	matagord.	A	3.5	47.33	3.78	15.79	37.57	3.74	14.52
137	1882.7	L.	matagord.	A	3.5	28.12	3.99	14.54			
137	1882.7	L.	matagord.	A	3.5	37.26	3.45	13.22			
137	1882.7	L.	matagord.	A	3.5	35.56	3.72	12.33			
141	1879.4	L.	matagord.	A	3.5	34.89	3.87	17.01	34.89	3.87	17.01
143	1877.8	L.	matagord.	A	3.5	39.58	3.99	15.32	40.26	3.84	14.80
143	1877.8	L.	matagord.	A	3.5	42.35	3.89	13.19			
143	1877.8	L.	matagord.	A	3.5	38.87	3.65	15.90			

Bob Allen Keys Core 6A

1	1994.0	P.	setipunct.	A or A-1	1	18.70	4.35	11.43	18.70	4.35	11.43
1	1994.0	P.	setipunct.	A or A-1	2	31.30	3.91	12.76			
1	1994.0	P.	setipunct.	A or A-1	2	30.50	4.03	13.05			
1	1994.0	P.	setipunct.	A-2?	2	25.22	4.11	12.52			
3	1992.1	P.	setipunct.	A	2	20.27	3.93	11.57	20.27	3.93	11.57
3	1992.1	P.	setipunct.	A-1 or A-2	1	20.88	4.58	12.25			
3	1992.1	P.	setipunct.	A-3	1	20.12	3.99	12.55			
3	1992.1	P.	setipunct.	A-2	1	22.82	4.16	12.61			

Table 3.—Continued.

Depth (cm)	Year	Genus	Species	Molt	VPI	Mg/Ca	Sr/Ca	Na/Ca	Mg/Ca (avg.)	Sr/Ca (avg.)	Na/Ca (avg.)
9	1986.3	<i>P.</i>	<i>setipunct.</i>	A or A-1	2	21.97	4.14	13.92	21.81	4.16	14.15
9	1986.3	<i>P.</i>	<i>setipunct.</i>	A or A-1	2	21.65	4.18	14.39			
9	1986.3	<i>P.</i>	<i>setipunct.</i>	A-2	2	31.15	4.11	11.82			
15	1980.6	<i>P.</i>	<i>setipunct.</i>	A	1	22.22	4.15	14.27	22.22	4.15	14.27
15	1980.6	<i>P.</i>	<i>setipunct.</i>	A-1	1	17.69	4.14	11.27			
15	1980.6	<i>P.</i>	<i>setipunct.</i>	A-4	1	27.89	3.98	8.85			
17	1978.7	<i>P.</i>	<i>setipunct.</i>	A-2	1	32.08	4.44	13.65	26.53	4.39	13.19
19	1976.7	<i>P.</i>	<i>setipunct.</i>	A-2?	2	26.26	3.99	11.79			
19	1976.7	<i>P.</i>	<i>setipunct.</i>	A-3	2	19.93	3.94	11.08			
21	1974.8	<i>P.</i>	<i>setipunct.</i>	A?	1	22.57	4.30	12.83	23.03	4.11	13.00
21	1974.8	<i>P.</i>	<i>setipunct.</i>	A	1	30.49	4.48	13.54			
23	1972.9	<i>P.</i>	<i>setipunct.</i>	A	1	23.03	4.11	13.00			
25	1971.0	<i>P.</i>	<i>setipunct.</i>	A	2	17.63	4.11	14.17	17.97	4.13	14.24
25	1971.0	<i>P.</i>	<i>setipunct.</i>	A	2	18.31	4.16	14.31			
27	1969.0	<i>P.</i>	<i>setipunct.</i>	A	1	22.56	4.12	11.35			
27	1969.0	<i>P.</i>	<i>setipunct.</i>	A	2	21.08	3.51	10.53	21.82	3.82	10.94
31	1965.2	<i>P.</i>	<i>setipunct.</i>	A	2	24.66	4.55	13.69			
31	1965.2	<i>P.</i>	<i>setipunct.</i>	A or A-1	2	24.15	4.21	12.79			
33	1963.3	<i>P.</i>	<i>setipunct.</i>	A	2	21.70	4.41	14.40	21.42	4.44	14.38
33	1963.3	<i>P.</i>	<i>setipunct.</i>	A	2	21.15	4.46	14.36			
35	1961.3	<i>P.</i>	<i>setipunct.</i>	A	2	24.04	4.24	12.34			
35	1961.3	<i>P.</i>	<i>setipunct.</i>	A	2	22.50	4.13	11.87	20.35	4.05	12.25
37	1959.4	<i>P.</i>	<i>setipunct.</i>	A	2	20.44	4.00	10.83			
37	1959.4	<i>P.</i>	<i>setipunct.</i>	A	2	20.26	4.11	13.67			
41	1955.6	<i>P.</i>	<i>setipunct.</i>	A	2	16.36	4.09	12.47	16.36	4.09	12.47
43	1953.7	<i>P.</i>	<i>setipunct.</i>	A	2	17.39	3.82	12.50			
43	1953.7	<i>P.</i>	<i>setipunct.</i>	A	2	17.69	4.22	12.40			
47	1949.8	<i>P.</i>	<i>setipunct.</i>	A	2	19.61	4.36	13.72	19.46	4.37	13.96
47	1949.8	<i>P.</i>	<i>setipunct.</i>	A	2	19.32	4.38	14.20			
59	1938.3	<i>P.</i>	<i>setipunct.</i>	A	2	24.36	3.83	10.39			
63	1934.4	<i>P.</i>	<i>setipunct.</i>	A	1	24.49	4.12	12.59	23.34	4.17	12.91
63	1934.4	<i>P.</i>	<i>setipunct.</i>	A	2	22.19	4.21	13.23			
67	1930.6	<i>P.</i>	<i>setipunct.</i>	A	2	25.86	4.26	13.93			
69	1928.7	<i>P.</i>	<i>setipunct.</i>	A	1	20.71	4.39	14.09	20.71	4.39	14.09
71	1926.7	<i>P.</i>	<i>setipunct.</i>	A	2	29.29	4.22	13.29			
71	1926.7	<i>P.</i>	<i>setipunct.</i>	A	2	23.36	4.25	12.02			
77	1921.0	<i>P.</i>	<i>setipunct.</i>	A	2	18.58	4.07	13.04	18.58	4.07	13.04
79	1919.0	<i>P.</i>	<i>setipunct.</i>	A	2	18.91	3.94	12.13			
79	1919.0	<i>P.</i>	<i>setipunct.</i>	A	1	20.96	4.32	12.82			
83	1915.2	<i>P.</i>	<i>setipunct.</i>	A	2	21.36	4.14	13.46	21.36	4.14	13.46
85	1913.3	<i>P.</i>	<i>setipunct.</i>	A	2	23.06	4.11	13.03			
87	1911.3	<i>P.</i>	<i>setipunct.</i>	A	2	21.83	4.11	12.43			
87	1911.3	<i>P.</i>	<i>setipunct.</i>	A	2	20.09	4.35	12.16	20.53	4.31	12.40
91	1907.5	<i>P.</i>	<i>setipunct.</i>	A	2	24.06	4.73	12.07			
91	1907.5	<i>P.</i>	<i>setipunct.</i>	A	2	17.00	3.90	12.73			
93	1905.6	<i>P.</i>	<i>setipunct.</i>	A	2	16.90	4.27	13.58	16.90	4.27	13.58
101	1897.9	<i>P.</i>	<i>setipunct.</i>	A	2	17.82	4.03	11.15			
101	1897.9	<i>P.</i>	<i>setipunct.</i>	A	2	19.45	4.34	10.96			
105	1894.0	<i>P.</i>	<i>setipunct.</i>	A	2	23.10	4.26	12.42	23.10	4.26	12.42
107	1892.1	<i>P.</i>	<i>setipunct.</i>	A	1	22.67	4.43	11.92			
107	1892.1	<i>P.</i>	<i>setipunct.</i>	A	1	22.90	4.32	11.98			
109	1890.2	<i>P.</i>	<i>setipunct.</i>	A	2	19.20	4.02	12.49	19.20	4.02	12.49
113	1886.3	<i>P.</i>	<i>setipunct.</i>	A	2	15.02	4.08	11.43			
113	1886.3	<i>P.</i>	<i>setipunct.</i>	A		19.87	4.11	12.35			
117	1882.5	<i>P.</i>	<i>setipunct.</i>	A	2	22.47	4.29	13.09	17.43	3.89	11.93
121	1878.7	<i>P.</i>	<i>setipunct.</i>	A	2	19.04	4.05	12.17			
125	1874.8	<i>P.</i>	<i>setipunct.</i>	A	2	16.69	3.31	10.27			
125	1874.8	<i>P.</i>	<i>setipunct.</i>	A	2	18.18	4.48	13.59	17.07	3.99	12.14
127	1872.9	<i>P.</i>	<i>setipunct.</i>	A	2	20.75	4.03	12.62			
133	1867.1	<i>P.</i>	<i>setipunct.</i>	A	1	16.55	4.18	12.81			

Table 3.—Continued.

Depth (cm)	Year	Genus	Species	Molt	VPI	Mg/Ca	Sr/Ca	Na/Ca	Mg/Ca (avg.)	Sr/Ca (avg.)	Na/Ca (avg.)
133	1867.1	<i>P.</i>	<i>setipunct.</i>	A	1	17.59	3.80	11.47			
135	1865.2	<i>P.</i>	<i>setipunct.</i>	A	2	24.55	4.05	9.88			
137	1863.3	<i>P.</i>	<i>setipunct.</i>	A	2	24.10	4.23	12.76	23.69	4.14	12.72
137	1863.3	<i>P.</i>	<i>setipunct.</i>	A		23.29	4.05	12.68			
139	1861.3	<i>P.</i>	<i>setipunct.</i>	A	2	21.34	4.30	13.07			
141	1859.4	<i>P.</i>	<i>setipunct.</i>	A	2	17.08	4.09	13.10			
141	1859.4	<i>P.</i>	<i>setipunct.</i>	A		16.73	4.14	12.24			
141	1859.4	<i>P.</i>	<i>setipunct.</i>	A	2	24.98	4.18	10.84			
143	1857.5	<i>P.</i>	<i>setipunct.</i>	A	2	20.78	4.25	12.39	19.82	4.15	11.46
143	1857.5	<i>P.</i>	<i>setipunct.</i>	A	2	16.66	3.61	9.63			
143	1857.5	<i>P.</i>	<i>setipunct.</i>	A	2	22.02	4.59	12.36			
145	1855.6	<i>P.</i>	<i>setipunct.</i>	A	2	19.00	4.56	11.44	20.21	4.02	10.71
145	1855.6	<i>P.</i>	<i>setipunct.</i>	A	2	21.42	3.48	9.98			
147	1853.7	<i>P.</i>	<i>setipunct.</i>	A	2	22.82	4.31	10.31	22.82	4.31	10.31
151	1849.8	<i>P.</i>	<i>setipunct.</i>	A	2	17.94	4.02	11.66	17.94	4.02	11.66
153	1847.9	<i>P.</i>	<i>setipunct.</i>	A	2	27.13	4.39	12.71	23.29	4.18	11.58
153	1847.9	<i>P.</i>	<i>setipunct.</i>	A	2	19.46	3.97	10.46			
155	1846.0	<i>P.</i>	<i>setipunct.</i>	A	2	22.78	4.11	12.68	20.11	4.14	12.47
155	1846.0	<i>P.</i>	<i>setipunct.</i>	A	2	17.44	4.17	12.26			
157	1844.0	<i>P.</i>	<i>setipunct.</i>	A	2	20.48	4.15	12.64	20.48	4.15	12.64
<i>Little Madeira Core T24</i>											
1	1991.4	<i>P.</i>	<i>setipunct.</i>	A	2	21.07	3.23	8.64	26.66	3.58	9.59
1	1991.4	<i>P.</i>	<i>setipunct.</i>	A	2	32.26	3.93	10.54			
11	1955.7	<i>P.</i>	<i>setipunct.</i>	A	1	30.72	3.58	10.00	30.70	3.60	10.13
11	1955.7	<i>P.</i>	<i>setipunct.</i>	—	—	30.68	3.62	10.26			
27	1898.6	<i>P.</i>	<i>setipunct.</i>	A?	3	23.17	4.12	9.96	23.17	4.12	9.96
33	1877.1	<i>P.</i>	<i>setipunct.</i>	A	3	25.03	3.97	8.64	25.03	3.97	8.64
37	1862.9	<i>P.</i>	<i>setipunct.</i>	A	3	19.53	4.28	8.23	21.47	4.25	9.64
37	1862.9	<i>P.</i>	<i>setipunct.</i>	A	3	23.41	4.22	11.05			
39	1855.7	<i>P.</i>	<i>setipunct.</i>	A	3	27.55	4.21	10.19	27.55	4.21	10.19
49	1820.0	<i>P.</i>	<i>setipunct.</i>	A	3	23.32	4.16	6.74	23.32	4.16	6.74
53	1805.7	<i>P.</i>	<i>setipunct.</i>	A	3	29.65	4.44	10.03	29.65	4.44	10.03
59	1784.3	<i>P.</i>	<i>setipunct.</i>	A	3	25.26	3.82	8.92	25.26	3.82	8.92
79	1712.9	<i>P.</i>	<i>setipunct.</i>	A?	3	25.60	4.61	8.49	25.60	4.61	8.49
<i>Park Key Core 23A</i>											
Site 11	1998.0	<i>L.</i>	<i>matagord.</i>		—	39.23	3.839	14.895	39.23	3.839	14.895
1	1993.7	<i>L.</i>	<i>matagord.</i>	A	—	37.168	3.839	15.444	35.29	3.89	18.82
1	1993.7	<i>L.</i>	<i>matagord.</i>	A	—	31.848	4.021	17.609			
1	1993.7	<i>L.</i>	<i>matagord.</i>	A	—	36.855	3.822	23.407			
3	1991.2	<i>L.</i>	<i>matagord.</i>	A	—	32.279	3.735	16.441	35.69	3.77	16.78
3	1991.2	<i>L.</i>	<i>matagord.</i>	A	—	37.027	3.769	16.880			
3	1991.2	<i>L.</i>	<i>matagord.</i>	A	—	37.754	3.801	17.019			
5	1988.6	<i>L.</i>	<i>matagord.</i>	A	—	32.898	3.698	14.916	37.42	3.67	15.89
5	1988.6	<i>L.</i>	<i>matagord.</i>	A	—	32.463	3.391	14.189			
5	1988.6	<i>L.</i>	<i>matagord.</i>	A	—	46.902	3.919	18.559			
7	1986.0	<i>L.</i>	<i>matagord.</i>	A	—	35.742	4.021	19.459	40.07	3.96	16.22
7	1986.0	<i>L.</i>	<i>matagord.</i>	A	—	46.036	3.907	14.429			
7	1986.0	<i>L.</i>	<i>matagord.</i>	A	—	38.435	3.956	14.765			
9	1983.5	<i>L.</i>	<i>matagord.</i>	A	—	37.972	3.931	17.307	36.89	3.73	16.92
9	1983.5	<i>L.</i>	<i>matagord.</i>	A	—	31.471	3.517	17.574			
9	1983.5	<i>L.</i>	<i>matagord.</i>	A	—	41.234	3.749	15.879			
11	1980.9	<i>L.</i>	<i>matagord.</i>	A	—	35.527	3.609	15.149	37.56	3.78	15.90
11	1980.9	<i>L.</i>	<i>matagord.</i>	A	—	33.892	3.804	13.350			
11	1980.9	<i>L.</i>	<i>matagord.</i>	A	—	43.266	3.941	19.202			
13	1978.3	<i>L.</i>	<i>matagord.</i>	A	—	33.939	3.853	14.738	41.27	3.84	17.41
13	1978.3	<i>L.</i>	<i>matagord.</i>	A	—	48.610	3.831	20.084			
15	1975.8	<i>L.</i>	<i>matagord.</i>	A	—	34.569	4.039	14.296	34.92	3.86	13.74
15	1975.8	<i>L.</i>	<i>matagord.</i>	A	—	35.272	3.687	13.189			
17	1973.2	<i>L.</i>	<i>matagord.</i>	A	—	36.764	3.692	19.534	38.09	3.72	16.40

Table 3.—Continued.

Depth (cm)	Year	Genus	Species	Molt	VPI	Mg/Ca	Sr/Ca	Na/Ca	Mg/Ca (avg.)	Sr/Ca (avg.)	Na/Ca (avg.)
17	1973.2	<i>L.</i>	<i>matagord.</i>	A	—	39.529	3.834	13.869			
17	1973.2	<i>L.</i>	<i>matagord.</i>	A	—	37.991	3.627	15.795			
19	1970.6	<i>L.</i>	<i>matagord.</i>	A	—	40.801	3.941	16.625	40.81	3.90	17.82
19	1970.6	<i>L.</i>	<i>matagord.</i>	A	—	46.646	3.505	17.558			
19	1970.6	<i>L.</i>	<i>matagord.</i>	A	—	34.976	4.248	19.266			
21	1968.1	<i>L.</i>	<i>matagord.</i>	A	—	43.454	3.955	18.219	37.96	3.90	17.42
21	1968.1	<i>L.</i>	<i>matagord.</i>	A	—	38.430	3.916	18.228			
21	1968.1	<i>L.</i>	<i>matagord.</i>	A	—	31.993	3.815	15.805			
23	1965.5	<i>L.</i>	<i>matagord.</i>	A	—	41.083	3.730	13.934	43.38	3.78	14.53
23	1965.5	<i>L.</i>	<i>matagord.</i>	A	—	44.853	3.805	17.531			
23	1965.5	<i>L.</i>	<i>matagord.</i>	A	—	44.190	3.815	12.135			
25	1962.9	<i>L.</i>	<i>matagord.</i>	A	—	43.813	3.832	14.306	35.44	3.47	12.49
25	1962.9	<i>L.</i>	<i>matagord.</i>	A	—	27.063	3.099	10.673			
27	1960.4	<i>L.</i>	<i>matagord.</i>	A	—	37.161	3.845	15.234	37.33	3.76	16.25
27	1960.4	<i>L.</i>	<i>matagord.</i>	A	—	35.081	3.762	14.894			
27	1960.4	<i>L.</i>	<i>matagord.</i>	A	—	39.754	3.661	18.617			
29	1957.8	<i>L.</i>	<i>matagord.</i>	A	—	42.313	4.079	14.168	38.62	4.05	14.65
29	1957.8	<i>L.</i>	<i>matagord.</i>	A	—	34.934	4.025	15.124			
31	1955.3	<i>L.</i>	<i>matagord.</i>	A	—	38.633	3.834	18.052	41.13	3.84	15.74
31	1955.3	<i>L.</i>	<i>matagord.</i>	A	—	36.882	3.639	15.555			
31	1955.3	<i>L.</i>	<i>matagord.</i>	A	—	47.863	4.055	13.613			
33	1952.7	<i>L.</i>	<i>matagord.</i>	A	—	38.465	3.572	18.343			
35	1950.1	<i>L.</i>	<i>matagord.</i>	A	—	32.028	3.720	14.424	37.74	3.73	15.14
35	1950.1	<i>L.</i>	<i>matagord.</i>	A	—	35.132	3.618	15.580			
35	1950.1	<i>L.</i>	<i>matagord.</i>	A	—	46.068	3.852	15.419			
37	1947.6	<i>L.</i>	<i>matagord.</i>	A	—	39.966	3.877	17.063	41.98	4.01	19.26
37	1947.6	<i>L.</i>	<i>matagord.</i>	A	—	36.811	3.928	17.330			
37	1947.6	<i>L.</i>	<i>matagord.</i>	A	—	49.168	4.240	23.390			
39	1945.0	<i>L.</i>	<i>matagord.</i>	A	—	37.609	3.710	16.161	37.61	3.71	16.16
41	1942.4	<i>L.</i>	<i>matagord.</i>	A	—	39.738	3.832	11.676	41.56	4.02	13.14
41	1942.4	<i>L.</i>	<i>matagord.</i>	A	—	43.387	4.214	14.597			
43	1939.9	<i>L.</i>	<i>matagord.</i>	A	—	36.224	3.436	14.897	36.85	3.81	16.27
43	1939.9	<i>L.</i>	<i>matagord.</i>	A	—	40.645	4.357	19.004			
43	1939.9	<i>L.</i>	<i>matagord.</i>	A	—	33.668	3.645	14.923			
45	1937.3	<i>L.</i>	<i>matagord.</i>	A	—	40.307	3.804	16.482	38.97	3.79	16.27
45	1937.3	<i>L.</i>	<i>matagord.</i>	A	—	38.335	3.540	16.605			
45	1937.3	<i>L.</i>	<i>matagord.</i>	A	—	38.279	4.019	15.730			
47	1934.7	<i>L.</i>	<i>matagord.</i>	A	—	37.157	3.935	16.233	35.59	3.59	15.40
47	1934.7	<i>L.</i>	<i>matagord.</i>	A	—	34.743	3.170	13.040			
47	1934.7	<i>L.</i>	<i>matagord.</i>	A	—	34.881	3.667	16.925			
49	1932.2	<i>L.</i>	<i>matagord.</i>	A	—	33.969	3.978	15.483	40.46	4.24	14.55
49	1932.2	<i>L.</i>	<i>matagord.</i>	A	—	46.949	4.500	13.614			
51	1929.6	<i>L.</i>	<i>matagord.</i>	A	—	34.572	3.568	14.314	35.26	3.80	16.18
51	1929.6	<i>L.</i>	<i>matagord.</i>	A	—	35.948	4.032	18.054			
53	1927.1	<i>L.</i>	<i>matagord.</i>	A	—	30.785	3.751	20.072	36.24	3.69	16.16
53	1927.1	<i>L.</i>	<i>matagord.</i>	A	—	46.299	3.431	14.939			
53	1927.1	<i>L.</i>	<i>matagord.</i>	A	—	31.636	3.900	13.483			
55	1924.5	<i>L.</i>	<i>matagord.</i>	A	—	40.095	4.165	16.014	38.61	4.01	16.57
55	1924.5	<i>L.</i>	<i>matagord.</i>	A	—	37.119	3.855	17.116			
57	1921.9	<i>L.</i>	<i>matagord.</i>	A	—	39.917	3.587	17.332	38.61	3.68	16.91
57	1921.9	<i>L.</i>	<i>matagord.</i>	A	—	37.298	3.763	16.494			
59	1919.4	<i>L.</i>	<i>matagord.</i>	A	—	44.702	3.725	13.998	43.47	3.79	15.44
59	1919.4	<i>L.</i>	<i>matagord.</i>	A	—	42.021	3.638	15.739			
59	1919.4	<i>L.</i>	<i>matagord.</i>	A	—	43.679	4.002	16.583			
61	1916.8	<i>L.</i>	<i>matagord.</i>	A	—	37.332	4.188	16.794	42.33	3.90	17.35
61	1916.8	<i>L.</i>	<i>matagord.</i>	A	—	47.322	3.608	17.898			
65	1911.7	<i>L.</i>	<i>matagord.</i>	A	—	32.995	3.757	19.137	33.00	3.76	19.14
69	1960.5	<i>L.</i>	<i>matagord.</i>	A	—	31.379	3.681	16.232	35.54	3.67	16.12

Table 3.—Continued.

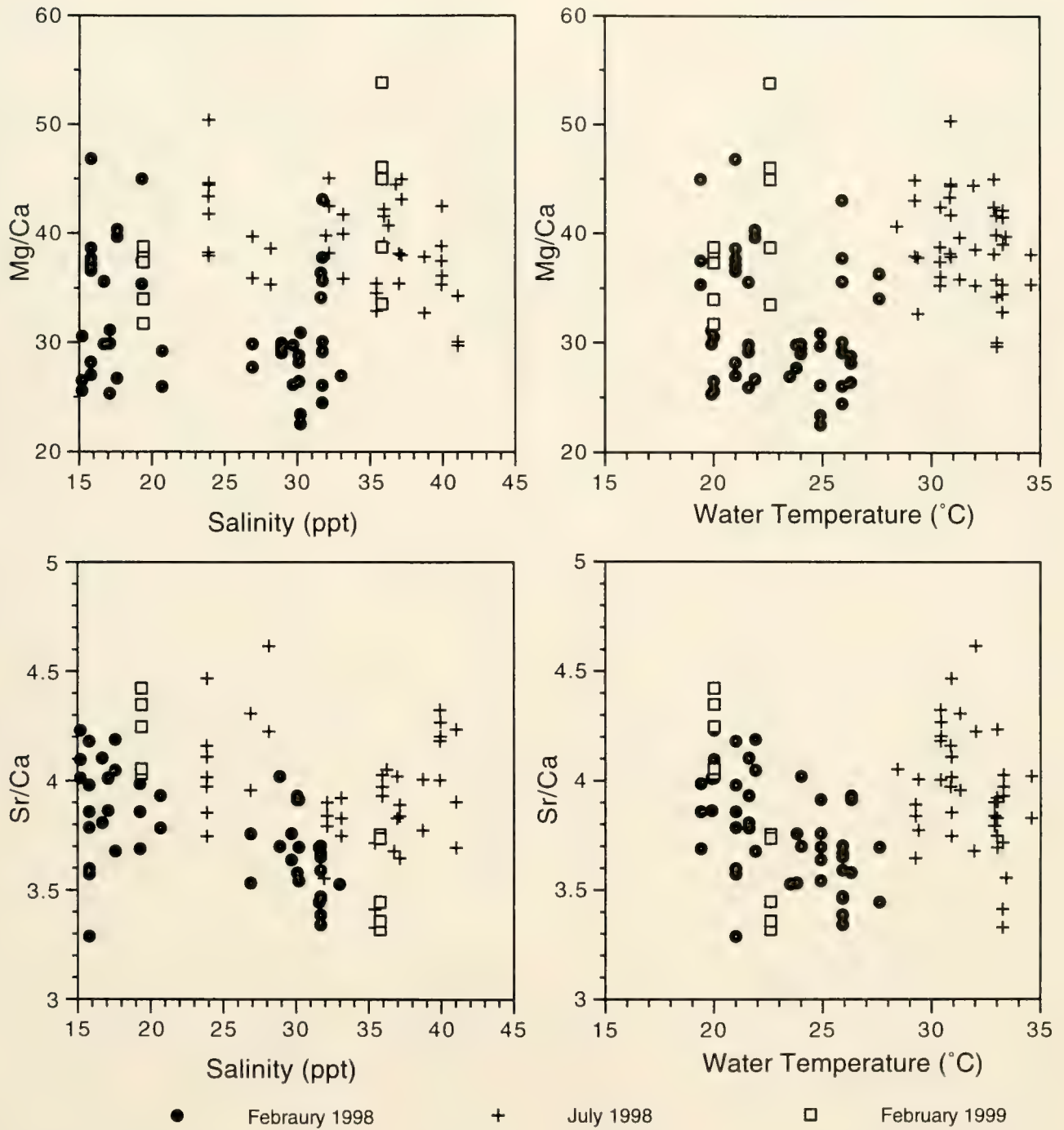
Depth (cm)	Year	Genus	Species	Molt	VPI	Mg/Ca	Sr/Ca	Na/Ca	Mg/Ca (avg.)	Sr/Ca (avg.)	Na/Ca (avg.)
69	1906.5	<i>L.</i>	<i>matagord.</i>	A	—	43.401	3.825	15.165			
69	1906.5	<i>L.</i>	<i>matagord.</i>	A	—	31.825	3.495	16.964			
71	1904.0	<i>L.</i>	<i>matagord.</i>	A	—	35.282	3.837	14.760	36.52	3.84	15.73
71	1904.0	<i>L.</i>	<i>matagord.</i>	A	—	40.568	3.877	18.267			
71	1904.0	<i>L.</i>	<i>matagord.</i>	A	—	33.704	3.792	14.161			
73	1901.4	<i>L.</i>	<i>matagord.</i>	A	—	35.505	3.648	16.474	36.84	3.98	15.98
73	1901.4	<i>L.</i>	<i>matagord.</i>	A	—	37.330	4.142	13.580			
73	1901.4	<i>L.</i>	<i>matagord.</i>	A	—	37.687	4.164	17.895			
75	1898.8	<i>L.</i>	<i>matagord.</i>	A	—	33.690	3.740	15.468	33.69	3.74	15.47
77	1896.3	<i>L.</i>	<i>matagord.</i>	A	—	38.411	3.959	19.349	35.02	3.85	17.00
77	1896.3	<i>L.</i>	<i>matagord.</i>	A	—	31.842	3.910	15.632			
77	1896.3	<i>L.</i>	<i>matagord.</i>	A	—	34.813	3.676	16.025			
79	1893.7	<i>L.</i>	<i>matagord.</i>	A	—	38.221	3.973	16.350	36.78	3.91	15.68
79	1893.7	<i>L.</i>	<i>matagord.</i>	A	—	36.782	4.064	15.975			
79	1893.7	<i>L.</i>	<i>matagord.</i>	A	—	35.334	3.700	14.722			
83	1888.6	<i>L.</i>	<i>matagord.</i>	A	—	36.244	3.954	13.319	39.36	3.83	15.19
83	1888.6	<i>L.</i>	<i>matagord.</i>	A	—	42.483	3.702	17.053			
83	1888.6	<i>L.</i>	<i>matagord.</i>	A	—	41.046	4.178	18.043			
<i>Manatee Bay Core MB1</i>											
1	—	<i>L.</i>	<i>matagord.</i>	A	3	41.13	3.62	17.07	35.86	3.81	15.34
1	—	<i>L.</i>	<i>matagord.</i>	A	3	33.03	3.89	14.76			
1	—	<i>L.</i>	<i>matagord.</i>	A	3	33.41	3.91	14.18			
3	—	<i>L.</i>	<i>matagord.</i>	A	4	39.51	4.09	12.61	38.91	3.96	17.26
3	—	<i>L.</i>	<i>matagord.</i>	A	3	37.17	4.23	24.29			
3	—	<i>L.</i>	<i>matagord.</i>	A	4	40.06	3.57	14.87			
5	—	<i>L.</i>	<i>matagord.</i>	A	3	35.38	3.71	14.47	33.91	3.92	14.44
5	—	<i>L.</i>	<i>matagord.</i>	A	3	35.29	3.85	15.87			
5	—	<i>L.</i>	<i>matagord.</i>	A	4	31.06	4.19	12.98			
7	—	<i>L.</i>	<i>matagord.</i>	A	4	41.53	3.92	13.68	36.28	4.00	15.09
7	—	<i>L.</i>	<i>matagord.</i>	A	3	34.15	3.83	15.56			
7	—	<i>L.</i>	<i>matagord.</i>	A	3	33.17	4.26	16.03			
9	—	<i>L.</i>	<i>matagord.</i>	A	4	35.26	4.31	16.77	35.44	4.10	15.37
9	—	<i>L.</i>	<i>matagord.</i>	A	4	37.17	4.22	15.25			
9	—	<i>L.</i>	<i>matagord.</i>	A	3	33.88	3.78	14.10			
11	—	<i>L.</i>	<i>matagord.</i>	A	4	38.94	3.91	15.39	37.54	4.05	15.37
11	—	<i>L.</i>	<i>matagord.</i>	A	4	35.81	4.13	16.93			
11	—	<i>L.</i>	<i>matagord.</i>	A	4	37.88	4.10	13.79			
13	—	<i>L.</i>	<i>matagord.</i>	A	3	35.27	3.61	14.47	36.26	3.86	13.92
13	—	<i>L.</i>	<i>matagord.</i>	A	3	33.73	3.60	10.24			
13	—	<i>L.</i>	<i>matagord.</i>	A	4	39.78	4.38	17.05			
15	—	<i>L.</i>	<i>matagord.</i>	A	3	34.36	4.31	16.24	39.38	4.15	15.09
15	—	<i>L.</i>	<i>matagord.</i>	A	3	45.33	4.13	15.35			
15	—	<i>L.</i>	<i>matagord.</i>	A	2	38.44	4.00	13.69			
19	—	<i>L.</i>	<i>matagord.</i>	A	2	32.05	3.59	12.09	37.46	3.76	12.89
19	—	<i>L.</i>	<i>matagord.</i>	A	3	41.22	3.61	13.66			
19	—	<i>L.</i>	<i>matagord.</i>	A	3	39.10	4.07	12.93			
21	—	<i>L.</i>	<i>matagord.</i>	A	2	37.63	3.93	18.29	40.02	3.93	13.92
21	—	<i>L.</i>	<i>matagord.</i>	A	2	47.40	3.77	11.13			
21	—	<i>L.</i>	<i>matagord.</i>	A	3	35.02	4.09	12.34			
25	—	<i>L.</i>	<i>matagord.</i>	A	3	37.48	3.64	13.36	40.75	3.87	15.33
25	—	<i>L.</i>	<i>matagord.</i>	A	3	44.60	3.72	16.79			
25	—	<i>L.</i>	<i>matagord.</i>	A	3	40.15	4.23	15.85			
27	—	<i>L.</i>	<i>matagord.</i>	A	3	30.07	3.68	15.78	31.66	3.55	14.75
27	—	<i>L.</i>	<i>matagord.</i>	A	3	25.17	3.40	14.11			
27	—	<i>L.</i>	<i>matagord.</i>	A	3	39.73	3.58	14.34			
29	—	<i>L.</i>	<i>matagord.</i>	A	3	32.18	4.00	13.21	36.51	3.81	14.28
29	—	<i>L.</i>	<i>matagord.</i>	A	4	38.27	3.47	14.85			
29	—	<i>L.</i>	<i>matagord.</i>	A	3	39.08	3.97	14.76			
31	—	<i>L.</i>	<i>matagord.</i>	A	3	46.53	3.52	12.85	40.31	3.47	13.22

Table 3.—Continued.

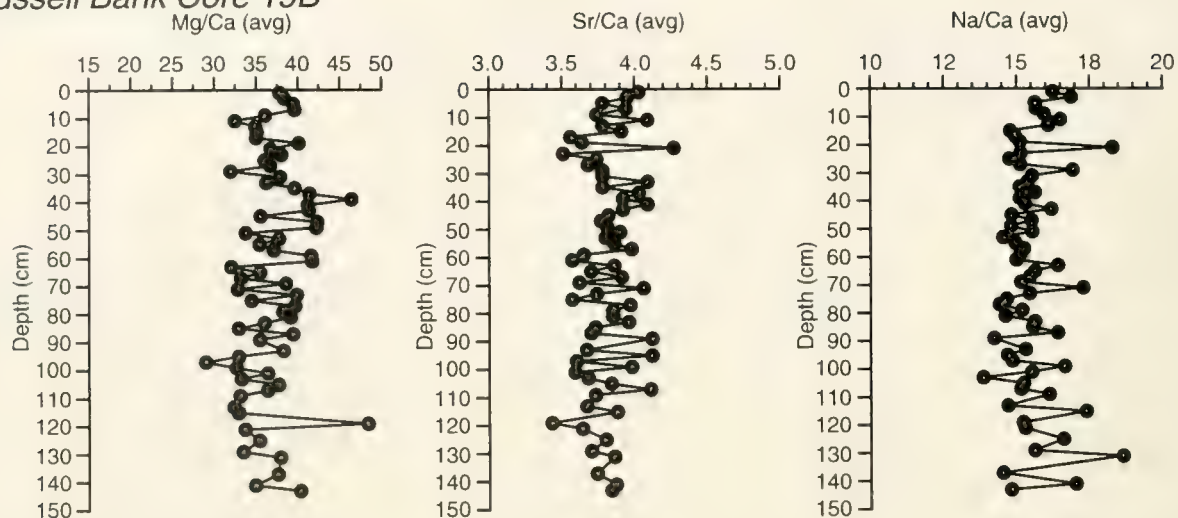
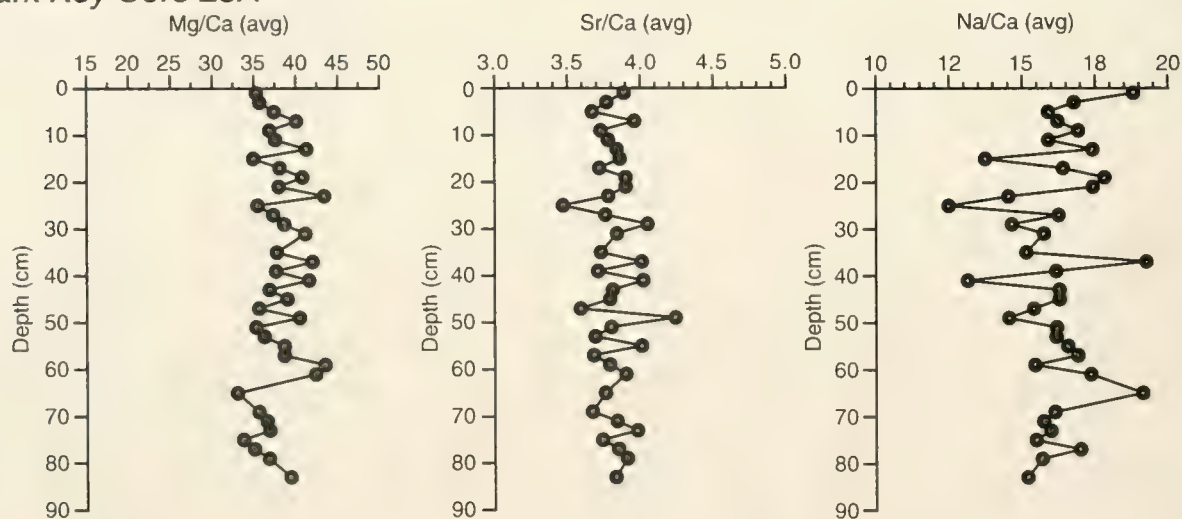
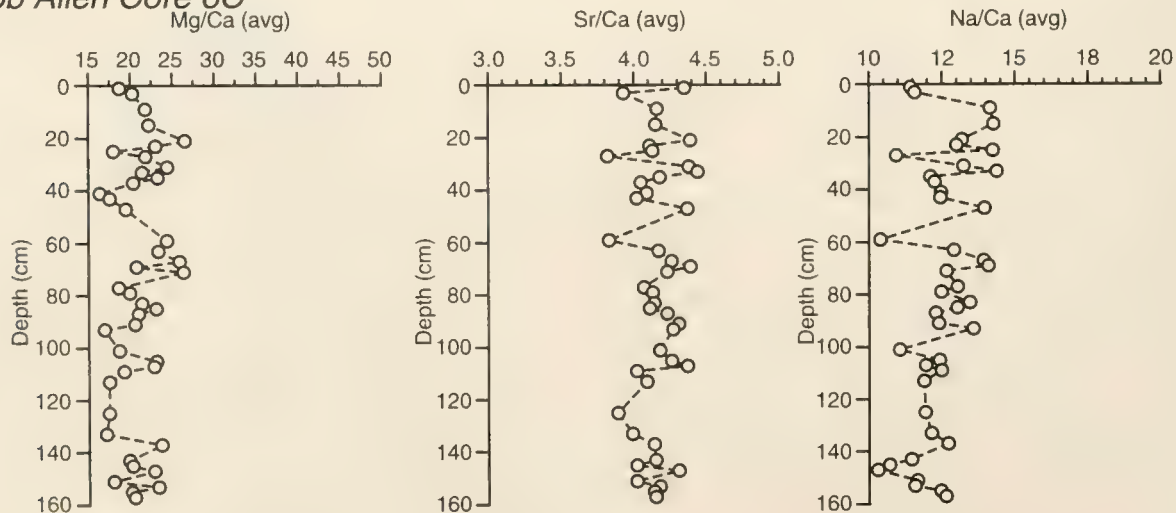
Depth (cm)	Year	Genus	Species	Molt	VPI	Mg/Ca	Sr/Ca	Na/Ca	Mg/Ca (avg.)	Sr/Ca (avg.)	Na/Ca (avg.)
31	—	<i>L.</i>	<i>matagord.</i>	A	2	34.09	3.43	13.58			
33	—	<i>L.</i>	<i>matagord.</i>	A	3	33.24	3.32	10.93	38.04	3.69	12.56
33	—	<i>L.</i>	<i>matagord.</i>	A	3	42.84	4.06	14.19			
35	—	<i>L.</i>	<i>matagord.</i>	A	4	31.02	3.56	14.80	34.18	3.71	15.46
35	—	<i>L.</i>	<i>matagord.</i>	A		37.34	3.86	16.12			
37	—	<i>L.</i>	<i>matagord.</i>	A	3	42.76	3.80	14.69	40.60	3.78	13.48
37	—	<i>L.</i>	<i>matagord.</i>	A	3	38.44	3.77	12.27			
39	—	<i>L.</i>	<i>matagord.</i>	A	3	36.24	3.58	14.14	41.04	3.63	14.30
39	—	<i>L.</i>	<i>matagord.</i>	A	3	40.93	3.55	15.08			
39	—	<i>L.</i>	<i>matagord.</i>	A	3	45.96	3.75	13.68			
41	—	<i>L.</i>	<i>matagord.</i>	A	3	41.12	3.30	11.88	37.72	3.71	12.72
41	—	<i>L.</i>	<i>matagord.</i>	A	2	39.08	3.91	14.16			
41	—	<i>L.</i>	<i>matagord.</i>	A	2	32.97	3.93	12.12			
43	—	<i>L.</i>	<i>matagord.</i>	A	3	35.84	3.93	14.50	35.84	3.93	14.50
45	—	<i>L.</i>	<i>matagord.</i>	A	3	36.79	3.64	12.61	31.17	3.66	13.17
45	—	<i>L.</i>	<i>matagord.</i>	A	4	25.55	3.67	13.74			
47	—	<i>L.</i>	<i>matagord.</i>	A	3	39.23	3.13	13.96	42.06	3.33	14.17
47	—	<i>L.</i>	<i>matagord.</i>	A	3	41.76	3.38	13.80			
47	—	<i>L.</i>	<i>matagord.</i>	A	3	45.18	3.49	14.75			
49	—	<i>L.</i>	<i>matagord.</i>	A	3	33.74	3.77	13.53	39.42	3.45	13.33
49	—	<i>L.</i>	<i>matagord.</i>	A	3	39.95	3.09	13.72			
49	—	<i>L.</i>	<i>matagord.</i>	A	3	44.58	3.47	12.73			
51	—	<i>L.</i>	<i>matagord.</i>	A	4	40.64	3.65	13.92	35.47	3.62	14.16
51	—	<i>L.</i>	<i>matagord.</i>	A	3	29.99	3.80	13.73			
51	—	<i>L.</i>	<i>matagord.</i>	A	4	35.79	3.41	14.82			
53	—	<i>L.</i>	<i>matagord.</i>	A	3	36.93	3.42	14.52	36.95	3.64	14.60
53	—	<i>L.</i>	<i>matagord.</i>	A	3	35.61	3.61	13.45			
53	—	<i>L.</i>	<i>matagord.</i>	A	2	38.31	3.90	15.82			
55	—	<i>L.</i>	<i>matagord.</i>	A	3	32.62	3.60	17.79	37.04	3.61	16.09
55	—	<i>L.</i>	<i>matagord.</i>	A	4	38.62	3.48	15.51			
55	—	<i>L.</i>	<i>matagord.</i>	A	3	39.87	3.75	14.98			
57	—	<i>L.</i>	<i>matagord.</i>	A	4	26.06	6.83	143.25	33.10	4.83	57.34
57	—	<i>L.</i>	<i>matagord.</i>	A	3	35.01	3.98	12.33			
57	—	<i>L.</i>	<i>matagord.</i>	A	3	38.22	3.67	16.44			
59	—	<i>L.</i>	<i>matagord.</i>	A	3	40.17	3.79	15.41	39.89	3.90	15.02
59	—	<i>L.</i>	<i>matagord.</i>	A	3	37.50	4.04	15.78			
59	—	<i>L.</i>	<i>matagord.</i>	A	2	42.00	3.88	13.87			
61	—	<i>L.</i>	<i>matagord.</i>	A	2	26.79	3.46	14.73	32.40	3.49	14.30
61	—	<i>L.</i>	<i>matagord.</i>	A	3	36.57	3.98	14.76			
61	—	<i>L.</i>	<i>matagord.</i>	A	3	33.83	3.05	13.40			
63	—	<i>L.</i>	<i>matagord.</i>	A	4	35.64	3.54	12.39	36.70	3.52	14.21
63	—	<i>L.</i>	<i>matagord.</i>	A	2	33.18	3.60	15.80			
63	—	<i>L.</i>	<i>matagord.</i>	A	3	41.26	3.42	14.44			
65	—	<i>L.</i>	<i>matagord.</i>	A	3	37.25	3.43	14.57	37.25	3.43	14.57
67	—	<i>L.</i>	<i>matagord.</i>	A	3	43.09	4.29	15.92	40.62	3.97	14.41
67	—	<i>L.</i>	<i>matagord.</i>	A	3	35.03	3.75	13.13			
67	—	<i>L.</i>	<i>matagord.</i>	A	4	43.74	3.86	14.19			
69	—	<i>L.</i>	<i>matagord.</i>	A	5	34.67	3.36	14.97	34.67	3.36	14.97
71	—	<i>L.</i>	<i>matagord.</i>	A	2	33.00	3.60	11.71	34.40	3.72	13.59
71	—	<i>L.</i>	<i>matagord.</i>	A	2	35.79	3.85	15.48			
73	—	<i>L.</i>	<i>matagord.</i>	A	3	35.69	3.64	14.28	37.16	3.81	14.20
73	—	<i>L.</i>	<i>matagord.</i>	A	3	47.17	3.79	14.32			
73	—	<i>L.</i>	<i>matagord.</i>	A		28.62	4.00	14.01			
75	—	<i>L.</i>	<i>matagord.</i>	A		36.67	3.99	15.10	41.07	4.00	16.15
75	—	<i>L.</i>	<i>matagord.</i>	A		45.46	4.02	17.20			
117	—	<i>P.</i>	<i>setipunct.</i>	A	5	24.49	3.91	8.94	23.96	3.61	9.07
117	—	<i>P.</i>	<i>setipunct.</i>	A	5	21.25	3.35	8.44			
117	—	<i>P.</i>	<i>setipunct.</i>	A	5	26.15	3.57	9.84			
115	—	<i>P.</i>	<i>setipunct.</i>	A	5	24.22	3.97	6.64	23.79	3.67	7.71

Table 3.—Continued.

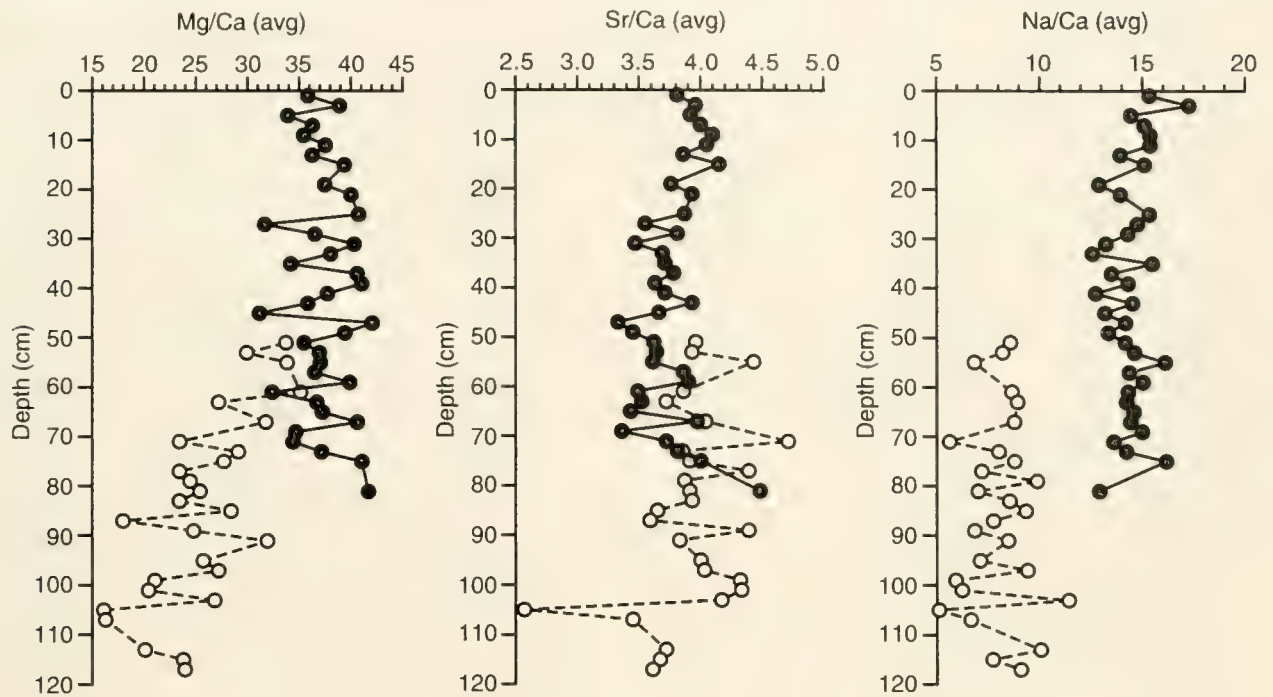
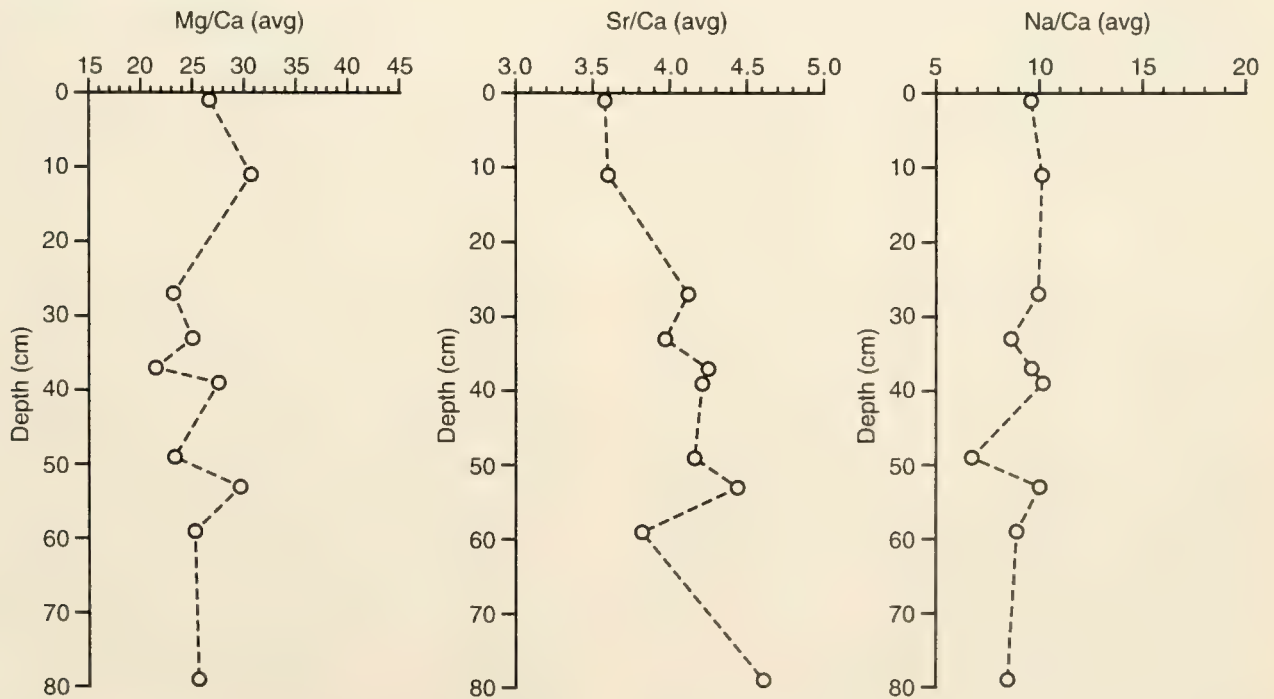
Depth (cm)	Year	Genus	Species	Molt	VPI	Mg/Ca	Sr/Ca	Na/Ca	Mg/Ca (avg.)	Sr/Ca (avg.)	Na/Ca (avg.)
115	—	P.	setipunct.	A	5	28.51	3.76	8.66			
115	—	P.	setipunct.	A	5	18.66	3.29	7.82			
113	—	P.	setipunct.	A	5	18.71	3.75	11.28	20.10	3.72	10.04
113	—	P.	setipunct.	A	5	21.49	3.70	8.80			
107	—	P.	setipunct.	A	5	19.49	3.22	6.60	16.28	3.45	6.64
107	—	P.	setipunct.	A	5	13.07	3.68	6.68			
105	—	P.	setipunct.	A	5	16.10	2.57	5.10	16.10	2.57	5.10
103	—	P.	setipunct.	A	5	25.47	4.08	10.90	26.83	4.17	11.41
103	—	P.	setipunct.	A	5	31.14	4.04	7.59			
103	—	P.	setipunct.	A	5	23.88	4.38	15.73			
101	—	P.	setipunct.	A	5	20.12	4.81	4.54	20.43	4.33	6.22
101	—	P.	setipunct.	A	5	20.74	3.86	7.90			
99	—	P.	setipunct.	A	5	17.99	4.38	5.58	21.05	4.32	5.91
99	—	P.	setipunct.	A	5	24.11	4.26	6.24			
97	—	P.	setipunct.	A	5	30.18	4.43	9.30	27.20	4.03	9.40
97	—	P.	setipunct.	A	5	25.90	3.86	8.88			
97	—	P.	setipunct.	A	5	25.53	3.79	10.01			
95	—	P.	setipunct.	A	5	23.52	3.97	7.01	25.71	4.00	7.10
95	—	P.	setipunct.	A	5	27.89	4.03	7.19			
93	—	P.	setipunct.	A	4	30.80	4.03	9.08			
93	—	P.	setipunct.	A	4	25.76	3.66	8.46			
91	—	P.	setipunct.	A	5	32.03	4.30	8.74	31.94	3.83	8.46
91	—	P.	setipunct.	A	5	31.85	3.36	8.18			
89	—	P.	setipunct.	A	5	21.24	4.86	6.03	24.80	4.39	6.83
89	—	P.	setipunct.	A	4	29.78	3.85	8.16			
89	—	P.	setipunct.	A	4	23.37	4.47	6.29			
87	—	P.	setipunct.	A	5	17.97	3.59	7.75	17.97	3.59	7.75
85	—	P.	setipunct.	A	5	28.42	3.65	9.32	28.42	3.65	9.32
83	—	P.	setipunct.	A	4	19.28	3.87	8.92	23.45	3.93	8.53
83	—	P.	setipunct.	A	4	27.84	3.91	9.88			
83	—	P.	setipunct.	A	3	23.23	4.03	6.79			
81	—	P.	setipunct.	A	4	25.42	3.91	7.00	25.42	3.91	7.00
81	—	P.	setipunct.	A	4	42.06	4.50	13.08	41.71	4.48	12.89
81	—	P.	setipunct.	A	4	41.37	4.45	12.69			
79	—	P.	setipunct.	A	2	28.97	3.73	9.94	24.47	3.87	9.87
79	—	P.	setipunct.	A	3	26.44	4.04	9.96			
79	—	P.	setipunct.	A	2	18.01	3.84	9.71			
77	—	P.	setipunct.	A	3	24.63	4.23	6.13	23.44	4.39	7.18
77	—	P.	setipunct.	A	5	22.26	4.54	8.23			
75	—	P.	setipunct.	A	5	33.64	3.55	7.86	27.71	3.91	8.78
75	—	P.	setipunct.	A	4	26.51	4.03	9.53			
75	—	P.	setipunct.	A	2	22.99	4.16	8.96			
73	—	P.	setipunct.	A	3	28.11	4.08	8.14	29.11	3.85	8.00
73	—	P.	setipunct.	A	3	27.03	3.64	7.77			
73	—	P.	setipunct.	A	4	32.20	3.83	8.08			
71	—	P.	setipunct.	A	3	28.29	4.16	8.31	23.44	4.71	5.62
71	—	P.	setipunct.	A	2	18.59	5.26	2.92			
67	—	P.	setipunct.	A	2	34.00	4.10	8.89	31.78	4.04	8.76
67	—	P.	setipunct.	A	3	29.56	3.97	8.63			
63	—	P.	setipunct.	A	3	27.20	3.72	8.92	27.20	3.72	8.92
61	—	P.	setipunct.	A	2	33.16	3.72	9.09	35.13	3.86	8.65
61	—	P.	setipunct.	A	3	37.09	3.99	8.21			
55	—	P.	setipunct.	A	4	33.83	4.43	6.82	33.83	4.43	6.82
53	—	P.	setipunct.	A	2	29.42	4.17	8.44	29.92	3.93	8.19
53	—	P.	setipunct.	A	3	30.41	3.70	7.95			
51	—	P.	setipunct.	A	3	33.73	3.96	8.57	33.73	3.96	8.57



Text-figure 6.—Mg/Ca and Sr/Ca ratios of shells of *Loxoconcha matagordensis* from modern vegetation samples plotted versus salinity and temperature at time of collection.

Russell Bank Core 19B**Park Key Core 23A****Bob Allen Core 6C**

Text-figure 7.—Mg/Ca, Sr/Ca, and Na/Ca ratios of fossil ostracode shells versus depth from sediment cores collected from Russell Bank, Park Key, Bob Allen Keys, Little Madeira Bay, and Manatee Bay. *Loxococoncha matagordensis* (filled circles); *Pereatocytheridea setipunctata* (open circles).

Manatee Bay Core MB1*Little Madeira Bay Core T24*

Text-figure 7.—Continued.

ligible which is further supported by the overlapping values obtained for down-core shells (below).

DETERMINATION OF PARTITION COEFFICIENTS

From the water and shell chemistry results, we determined the partition coefficients for Mg and Sr for *Loxoconcha matagordensis*. For these determinations we used the grand average of Mg/Ca and Sr/Ca ratios for all of the Florida Bay water samples (Table 1) and the grand average of Mg/Ca and Sr/Ca ratios measured on 171 modern shells (Table 2). The determinations also assume an average water temperature of 26.5°C (average calculated from over 100 February and July water temperature measurements from 1997 and 1998; Brewster-Wingard *et al.*, this volume). Under these conditions the following K_D are derived:

$$\begin{aligned} K_{D-Mg} &= (36.98 \text{ mmol/mol Mg/Ca}) \\ &\div (4980 \text{ mmol/mol Mg/Ca}) \\ &= 0.00743 \\ K_{D-Sr} &= (3.81 \text{ mmol/mol Sr/Ca}) \\ &\div (8.46 \text{ mmol/mol Sr/Ca}) \\ &= 0.4499 \end{aligned}$$

The K_{D-Mg} of 0.00743 is similar to the value of 0.00756 calculated from the Mg data reported for shells of living specimens of open-marine *Loxoconcha* by Cadot and Kaesler (1977). K_{D-Na} is not determined because Na is apparently a non-lattice bound foreign ion within calcite (Busenberg and Plummer 1985). The calculated K_D values are used below, in conjunction with the water me/Ca-salinity relationship in Florida Bay, to calculate estimates of past salinity of Florida Bay.

METAL/CA TRENDS IN FOSSIL SHELLS FROM SEDIMENT CORES

Down-core shell me/Ca ratios are listed in Table 3 and summarized in Text-figure 7, which include data from two genera. Although changes in average salinity and temperature are considered the primary factors in controlling ostracode shell chemistry, some of the high frequency variability in Mg/Ca ratios may result from a combination of other factors. These include: (a) secretion of shells during different seasons, reflecting strong seasonal fluctuations in temperature and salinity of Florida Bay, (b) bioturbational mixing of penecontemporaneous shells, and/or, (c) short-term (hours to days) variability in salinity and temperature at a site, which may not be representative of longer term conditions. In order to evaluate inter-annual- to decadal-scale variability, we minimized the high-frequency signal by calculating intrasample means for each me/Ca

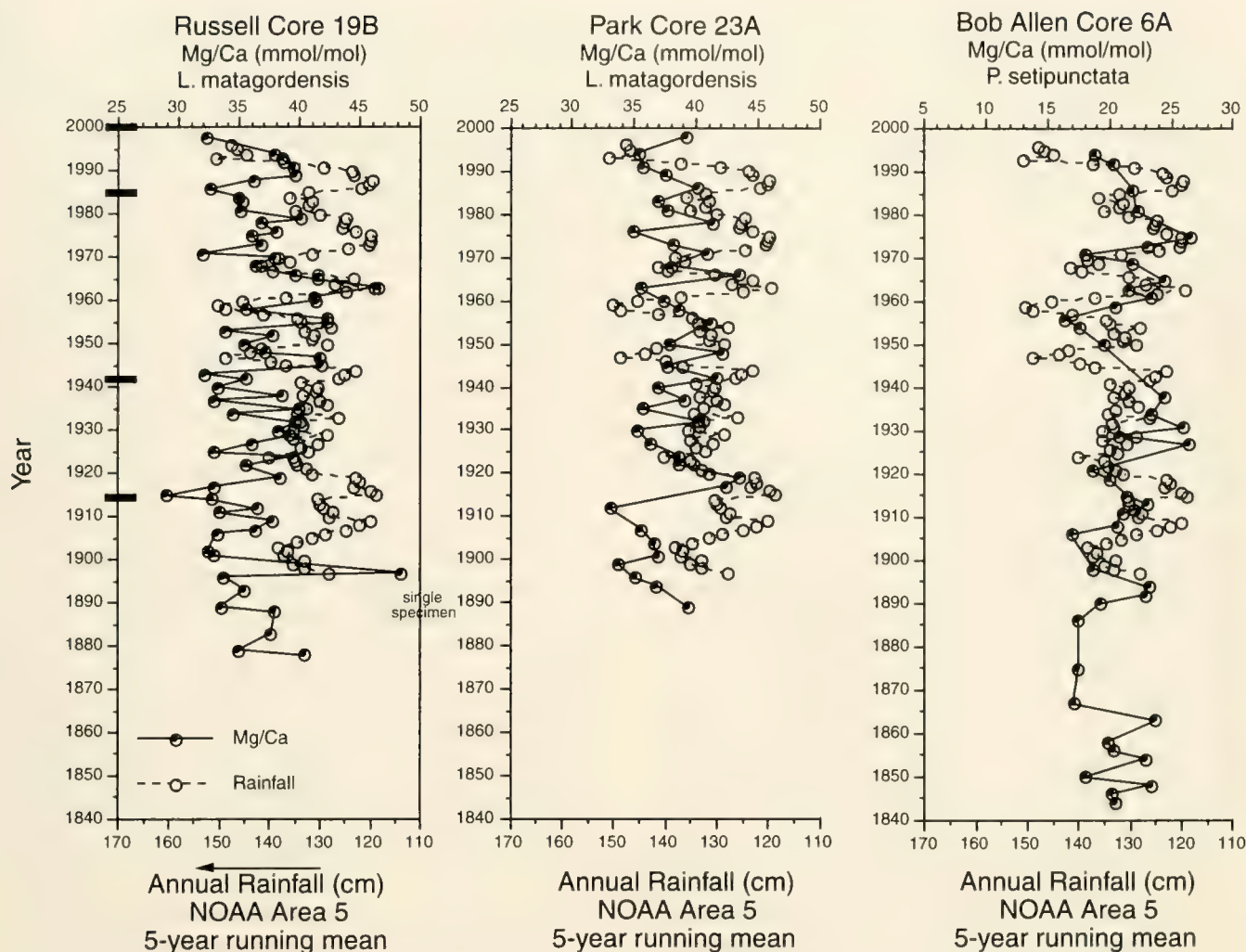
ratio and these are shown in Text-figure 7 versus core depth.

At Russell Bank, Park Key, and in Manatee Bay, Mg/Ca ratios for *Loxoconcha* fluctuate downcore between about 30 and 45 mmol/mol. Overall, the values for down-core specimens of *Loxoconcha* overlap with values obtained for modern *Loxoconcha* shells.

At Bob Allen Key and Little Madeira Bay, *Loxoconcha* was not as abundant downcore so we analyzed shells of the genus *Peratocytheridea*. Metal/Ca ratios for *Peratocytheridea*, however, appear to show systematic differences from those of *Loxoconcha*. In general, *Peratocytheridea* Mg/Ca ratios are offset toward lower values, averaging between 20 and 25 mmol/mol, values that are comparable to the lowest values obtained for modern *Loxoconcha* shells.

Sr/Ca ratios in *Peratocytheridea* shells generally show the opposite trend, yielding average values from 4.1 to 4.3 mmol/mol, approximately 15% higher than average values for *Loxoconcha*. Like Mg/Ca ratios, *Peratocytheridea* Na/Ca ratios are offset toward lower values relative to Na/Ca for *Loxoconcha*. The reason(s) for the differences observed between *Loxoconcha* and *Peratocytheridea* are unclear. The differences could be related to phylogenetic effects or might possibly indicate that these two genera preferentially secrete their adult shells at different times of the year, *i.e.*, *Peratocytheridea* primarily during the winter months.

Oscillations in the ostracode Sr/Ca ratio record from Russell Bank core generally show good correspondence with the pattern of variability observed in the Mg/Ca record (Text-fig. 7). However there are clear differences in the magnitude of the shifts in Sr/Ca and Mg/Ca and some of the changes appear to be out of phase. The reason for the variability between Sr/Ca and Mg/Ca records is not known. Possibly, it results from a differential response to changes in water temperature. Unlike the co-precipitation of Mg into CaCO_3 , which is positively correlated with temperature, Sr uptake may decrease with increasing temperature (reviewed in Morse and Mackenzie). Another possible factor is the effect of calcium carbonate production within Florida Bay. Biogenic aragonite, the dominant mineral produced in Florida Bay (Stockman *et al.*, 1967), co-precipitates large amounts of Sr at a Sr/Ca ratio that is similar to slightly lower than the Sr/Ca ratio of seawater. Thus, assuming continued high production of aragonite in Florida Bay, the Sr/Ca ratio of evaporatively concentrated, hypersaline bay waters would likely show only a slight increase in Sr/Ca, whereas the Mg/Ca ratio of the same waters would increase more sharply as Ca is removed by aragonite formation and Mg is virtually unaffected because it is all but excluded from the aragonite lattice. A third possible factor is the relatively small shift in Sr/Ca ratio



Text-figure 8.—Ostracode Mg/Ca ratios versus age from Russell, Park, and Bob Allen Keys sediment cores plotted along with 5-year running mean of annual rainfall. Solid bars along left axis mark years of strong El Niño events.

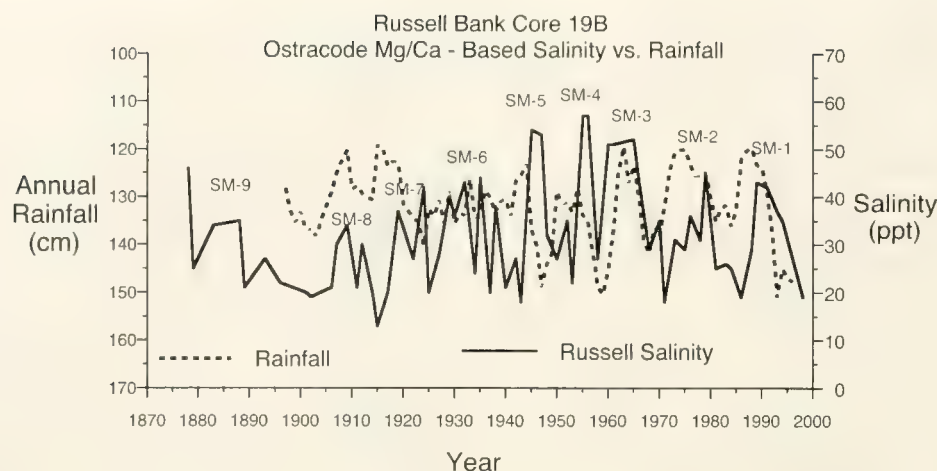
with salinity compared to that of Mg/Ca (Text-fig. 5). As a result of these potential temperature and water chemistry effects on Sr/Ca ratios, ostracode Mg/Ca ratios may be a more sensitive indicator of salinity changes in Florida Bay. This contention is generally supported by the higher dynamic range displayed by the down-core Mg/Ca records and the apparent correlation between shell Mg/Ca ratios and rainfall (below).

COMPARISON OF MG/CA AND HISTORICAL RAINFALL

To investigate whether the ostracode Mg/Ca ratios might be related to salinity variability, we compared downcore trends to historical rainfall records. We focus our discussion on the records from Russell, Bob Allen, and Park cores as they have the most robust chronostratigraphy. Text-figure 8 shows the down-core records of ostracode Mg/Ca ratios versus year. Because rainfall derived runoff from peninsular Florida is such

an important factor controlling the salinity of Florida Bay, we also show an instrumental record of south Florida annual rainfall which is available back to 1895 (NOAA Data Archive). The rainfall data are shown as a 5-year running mean to approximate the sampling frequency of the sediment cores.

In the Russell core, except for a single-specimen spike in the late 1890's, Mg/Ca ratios show a gradual decrease with little variation from the 1870's until around 1915, although the sampling resolution and age model are not as good as those for the upper part of this core. The succeeding interval, from 1915 to 1998 (the top most data point in the Russell record is an average of 4 living specimens collected from this site in 1998), is characterized by a slight overall increase in Mg/Ca that is punctuated by moderate to large-scale fluctuations. Eight periods of high Mg/Ca ratios are observed between 1900 and 1998 (Text-figure 8).



Text-figure 9.—Ostracode Mg/Ca-based salinity estimates for Russell core 19B and 5-year running mean of annual rainfall. Salinity derivation discussed in text. SM designates intervals of relative salinity maximum.

A comparison of the Mg/Ca record from the Russell core to the rainfall record reveals many similarities (Text-figure 8). For example, the rainfall data indicate that since the late 1950's there have been 3 quasi-decadal oscillations in precipitation over southern Florida. While the amplitude correspondence varies, within the resolution of sediment chronology, the three rainfall oscillations are matched one-for-one by oscillations in ostracode Mg/Ca ratios. Over this time interval, peaks in Mg/Ca occur during dry intervals in the early 1960's, mid-to-late 1970's, and the late 1980's, all periods of known hypersalinity within Florida Bay.

The decadal-scale correlation between rainfall and Mg/Ca persists in the earlier part of the records as well. Based on the rainfall record, this was a period of low amplitude rainfall oscillations relative to the last 50 years, a pattern that also appears in the Mg/Ca record. Thus, Mg/Ca and rainfall show a correspondence over multi-decadal timescales.

In addition to the longer-term correlation, it also appears that single-year climate events may be recorded in the Mg/Ca record. For example, four of the extreme minima over the last century closely correspond with years when the El Niño southern oscillation index (SOI) was strongly negative (Text-fig. 8). Typically, south Florida receives unusually high dry-season rainfall under such climate conditions (Douglas and Englehart, 1981), presumably leading to significantly lower salinity in Florida Bay.

Mg/Ca records from the Park and Bob Allen cores also correspond with the rainfall record, though the similarities are not as strong as in the Russell core. This may be a result of the lower resolution sampling within these cores or in the case of Bob Allen, due to an ecological effect related to *Peratocytheridea*. Another possibility is that these sites have stronger local

effects than Russell Bank. The Bob Allen and Park core sites appear to be located on the leeward side of complexes of islands and broad, shallow mudbanks which often experience wide temperature and salinity shifts relative to more open waters of Florida Bay. In contrast, the Russell Bank core site appears to be located in a much smaller lee on a narrow mudbank that extends out into open waters of the largest and deepest sub-bay within the eastern sector of Florida Bay. Thus, the Russell Bank site may be better situated to monitor large-scale changes in Florida Bay.

A PALEOSALINITY CURVE FOR CENTRAL FLORIDA BAY

Using the down-core *Loxoconcha* Mg/Ca ratios and the provisional K_{D-Mg} for *Loxoconcha*, we calculated estimates of past Mg/Ca ratios of Florida Bay water and converted them to estimates of past salinity based on the correlation between salinity and Mg/Ca_{water} (Text-fig. 5). Text-figure 9 shows ostracode Mg/Ca-based salinity estimates derived for Russell Bank and the south Florida rainfall record. Two extreme values at intervals equivalent to 1963 (91 ppt) and 1897 (113 ppt) are excluded from this plot. Calculated salinity estimates range from 13 to over 50 ppt. The overall average is 32 ppt with around two thirds of the values falling between 20 and 43 ppt.

The salinity estimates are quite reasonable, strongly overlapping with the range of instrumental salinity measurements taken at or near this site over the last 50 years which range from 10 to 55 ppt (Swart *et al.*, 1996, Halley *et al.*, 1995). One notable example is the salinity during the late 1980's which has been widely discussed in the context of Florida Bay seagrass dieoffs. Another is the high salinity recorded during the mid 1970s (Swart *et al.*, 1996). It is important to note that calculated salinity estimates that are greater

than ~42 ppt lie outside the range of our modern calibration data set and thus are unconstrained. These estimates may be high because the slope of best-fit curve to the $\text{Mg}/\text{Ca}_{\text{water}}$ versus salinity data increases continuously above 42 ppt, even though it appears that water Mg/Ca ratios begin to plateau near the seawater value. Thus, we might expect that ostracode shell Mg/Ca ratios would also plateau at a value around 38 mmol/mol, a value that is actually exceeded in a number of intervals in the Russell core, perhaps suggesting that Mg/Ca ratios of Florida Bay water increases further with increasing salinity.

An alternative interpretation of the trends in shell Mg/Ca is that the signal may be all or partially related to temperature. Temperature and salinity measurements collected seasonally for the last few years (Brewster-Wingard *et al.*, 2001) near the Russell core site suggest that temperature and salinity covary at this site, more so than at Bob Allen and Park Key. Given the thermodependence on Mg uptake in *Loxiconcha* and other ostracode genera (Cadot and Kaesler, 1977;

Dwyer *et al.*, 1995), the increased uptake of Mg resulting from higher water Mg/Ca ratios at higher salinity is likely further enhanced by an accompanying increase in water temperature. This may also help to explain the better correspondence between Mg/Ca and rainfall in the Russell core.

Until additional experiments in which adult ostracode shells are grown under controlled salinity and temperature conditions, the paleosalinity curve in Text-figure 9 must remain preliminary in nature. Still, the scale of variability in Mg/Ca ratios within all five cores and the estimated salinities are consistent with the hypothesis that salinity fluctuations occur over decadal timescales in Florida Bay. Moreover, the correspondence between interdecadal trends in rainfall and paleosalinity extremes indicates a strong climatic control on Florida Bay salinity. The shift to high amplitude oscillations in salinity after about 1950 seems to reflect a corresponding increase in rainfall extremes, but it may also reflect an alteration of the salinity regime due to human alteration of freshwater flow into Florida Bay.

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